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ENVIRONMENTAL EFFECTS OF NUCLEAR WEAPONS

By

Robert U. Ayres

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CHAPTER V

RELATIONS BETWEEN DOLLARS, DAMAGE, DISUTILITY AND RECOVERY

An important abstract concept used repeatedly in this study is that of social disutility. For our purposes, this notion can probably best be defined operationally in terms of a decision process, to allow one to deal with different kinds of value or different kinds of damage on the same footing.* One logical index of social utility, at least at the margin, is obviously money (dollars). Evidently money is the abstract unit which has naturally evolved in most societies to play precisely the required role: in modern Western civilization the free market classically fulfills the function of a continuous automatic decision-process for setting "margin exchange rates" between diverse values. The market place puts a price on such diverse "commodities" as life or health insurance, weapons for defense or murderers for hire, learning, and aesthetic satisfaction. While the things themselves are incomparable, their prices can be compared easily and (in some restricted sense) meaningfully.

Even at the margin we know there are some irrational and distorting influences on the peacetime "free" market, as for example "stimulated demand" and advertising, some of the dictates of fashion, effects of graduated taxation of incomes (and numerous loopholes), subsidies, protective tariffs, monopolistic or restrictive practices by either management or labor, etc. The existing cost-price structure would be greatly altered, and perhaps in practice further distorted as well, if a nuclear attack should take place; relative price levels (e.g. of food vs. luxuries) would probably change markedly, and possibly to some extent irrationally (at first), since the free market would certainly not operate at normal efficiency even if it were not suspended by government intervention. Thus prewar dollar value is an imperfect measure of utility, while actual postwar dollar value would be still less perfect as an index (though probably adequate for many purposes), even if it were calculable.

However, even with these drawbacks the prewar dollar value of a piece of land which implicitly includes factors such as proximity to transportation and markets, taxes, cost of local labor, etc., is likely to be a more relevant approximation to its "real" value than a technical calculation, e.g. of potential yield of energy (edible Calories). In the postwar context, of course, the prewar dollar value would have to be modified to take account of altered relationships (fallout on the land, transportation systems destroyed, markets destroyed). But again, most of the effects of these hypothetical events on dollar value are incalculable in advance. We shall, in this report, sometimes use the prewar dollar value

*There is a useful analogy with constitutional rights: legal "rights" often have no operational meaning until a process for determining their practical applicability is also defined, i.e. the civil courts.

of goods and services (GNP) as an index--not, however, taking it too seriously--for purposes of exposition in what follows. An approach to the development of other indices (in particular, postwar GNP) will be expounded later.

It must be conceded that dollar-value is itself a somewhat elusive concept. The "value of a dollar" is related in some complex fashion both to gross national wealth and to annual gross national product. The dollar value of fixed national assets such as land, structures and machinery are, in turn, determined by supply and demand under the conditions that assets (or shares thereof) are widely distributed and actively exchanged. Should either prerequisite, wide distribution or exchangeability, be altered, the nominal value would change. For example, if 90% of the land of CONUS were entailed in unbreakable trusts (as in Hawaii) the value of the residual, transferable 10% would rise sharply. The effect of widespread Sr-90 contamination might be superficially similar, e.g. a rise of price ("value") for the remaining land. Clearly the non-exchangeable fraction should not be valued at the same rate. In the foregoing example it is perhaps obvious that if the value of exchangeable land is inflated, then non-exchangeable land ought to be discounted (in a hypothetical census of postattack wealth). Nevertheless, the full extent of applicability of this principle is not self-evident.

The following table taken from Kahn[1] summarizes the wealth of the U.S. as of 1958.* The figures for 1965 would be about 25% larger (2.5 trillion).

TABLE 5-1

WEALTH OF THE UNITED STATES
(billions of dollars)

Structures:		
Residential	455	
Private (non-residential)	235	
Government (civilian)	200	
Institutional	30	
Government (military)	20	
		940
Equipment:		
Producers durables (non-farm)	205	
Consumer durables	200	
Military equipment	60	
Producers durables (farm)	20	
		485
Inventories:		
Business (non-farm)	115	
Farm	30	
Government (CCC and strategic)	30	
		175
Land, forests, and subsoil		375
TOTAL:		1,975

*An extension of estimates as of the end of 1958 compiled by the National Bureau of Economic Research. Does not include consumer non-durables (45),

The assets which contribute most directly to production are producers durables, manufacturing structures, and some fraction of business inventories and land--perhaps \$400 to \$500 billion in all. Of course, not all of this is actually at risk of physical destruction, but on the other hand, some part of what survives--while physically intact--may gain or lose in value, as remarked above, because of altered conditions of ownership distribution or exchangeability. We cannot, unfortunately, elucidate this question much beyond pointing out that the problem exists.

Although utility and disutility should perhaps be ultimately related to a concrete unit of measure such as money or GNP, it is important to recognize that the relationship is not simply linear.* As a metaphorical description of how disutility and a measure of value defined at the margin, such as dollars, might be related, one might make the intuitively reasonable supposition that it is about as easy (or difficult) to double a GNP of \$100 billion as it is to double \$1 billion. Looking at it another way, losing 50% of a fortune is not as disastrous as losing 99%, even though the dollar losses in the two cases may be the same. In the first case the loss can be recouped by a single doubling; in the second case the residue must be doubled about 6-1/2 times. If it takes a fixed time to double a given amount of money, the second case is about 6-1/2 times "worse" if we choose to measure "better" or "worse" in terms of the length of time needed to recoup.

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monetary metals (25), or foreign assets (30). The following is also suggestive: the value of all publicly traded shares of stock in corporations with 300 or more stockholders (6724 corporations) in January 1965 was \$647,676,000.[2] This figure overestimates to the extent that it counts more than once the value of shares of companies which are owned by other companies. On the other hand it underestimates to the extent that it omits small businesses, partnerships and closely held companies.

*A relation which roughly expresses how one might feel about the relationship between damage and disutility is the following: suppose that the ratio of a fractional change in disutility to an increment of damage is inversely proportional to the undamaged residue, and therefore approximately proportional to the cumulative fraction of damage already sustained. The statement reads:

$$\frac{\Delta \bar{U}}{\Delta D} \cong \frac{1}{1-D} \cong D \text{ for small } D,$$

where $\bar{U}$ stands for disutility and D stands for fractional damage (%). Expressing the increment as differentials and integrating, we obtain

$$\bar{U} = -\tau \ln(1-D), \text{ where } \tau \text{ is a constant of proportionality.}$$

In graphic form we have the dashed line in Figure 5.4 which increases, at first, at a slower rate than the fractional damage. However, the disutility increases faster and faster and approaches infinity as the level of destruction approaches 100%.

This relation is qualitatively in accord with our intuitive expectations, and we could, perhaps, make a case for raising it to the status of a definition of disutility. The principal objection is that it is <u>ad hoc</u>; it does not take any account of the perceived connection between disutility and the recovery process.

Implicit in this metaphor is an assumption that recovery occurs at a fixed constant rate, depending only on the size of the surviving base. In such a description the recovery process would be essentially analogous to compound interest growth or cellular multiplication.

It may be worthwhile looking more closely at the three tentative propositions which appear in the above two paragraphs: namely (1) that our understanding of the concept of disutility implies at least a rough proportionality to recovery time, (2) that recovery is analogous to growth, and (3) that growth is adequately described in terms of compound interest.

The first point is a question of choice. The metaphor supplied a justification for considering it to be reasonable to define disutility in terms of recovery time. For the present, therefore, we define disutility as the unrepaired damage (expressed by some convenient measure) integrated over time and connected by some, as yet unspecified, forward discount factor.

The validity of an analogy between recovery and growth (from a reduced base) can be better evaluated by looking at two alternative cases:

(i) compound interest (cellular multiplication),
(ii) organism growth.

In the first case, growth (i.e. recovery) is based on a uniform rate of increase of a base capital, $C = 1-D$, where D represents initial damage. As can easily be verified, growth in this case tends to be simply exponential; there is no natural limit (see Figure 5.1). As a recovery metaphor, the damage sustained at time, t_0, is simply a temporary setback, and after a finite time, T (where $T = -\tau \ln(1-D)$, the "economy" regains its former level and continues to expand.

In biological systems, by contrast, growth tends to be self-limiting, whence the rate of increase is proportional, not to the capital C, but to the difference between C and the ideal maximum corresponding to maturity or full growth (normalized to unity). Growth, or recovery, is assumed to follow an exponential law, but capital increases at a decelerating rather than an accelerating rate. The nearer to the normal state the system approaches, the less effective are the feedback mechanisms, such as production of hormones or antibodies, causing corrections (see Figure 5.2). A slightly different differential equation describes this model. Compound interest type growth--as in cancerous tissue--can be considered as a special case where the controlling feedback mechanisms fail to operate.

A better model would treat organism growth to maturity, or ecosystem growth to "climax," not merely in terms of generalized feedback mechanisms, but in terms of the actual constraints in operation. When this kind of model is used, the growth curve is seen to result from the interaction of several dynamic forces, e.g. reproduction rate versus death rate (involving

FIGURE 5.1

(i) ECONOMY (COMPOUND INTEREST) OR CELLULAR MULTIPLICATION

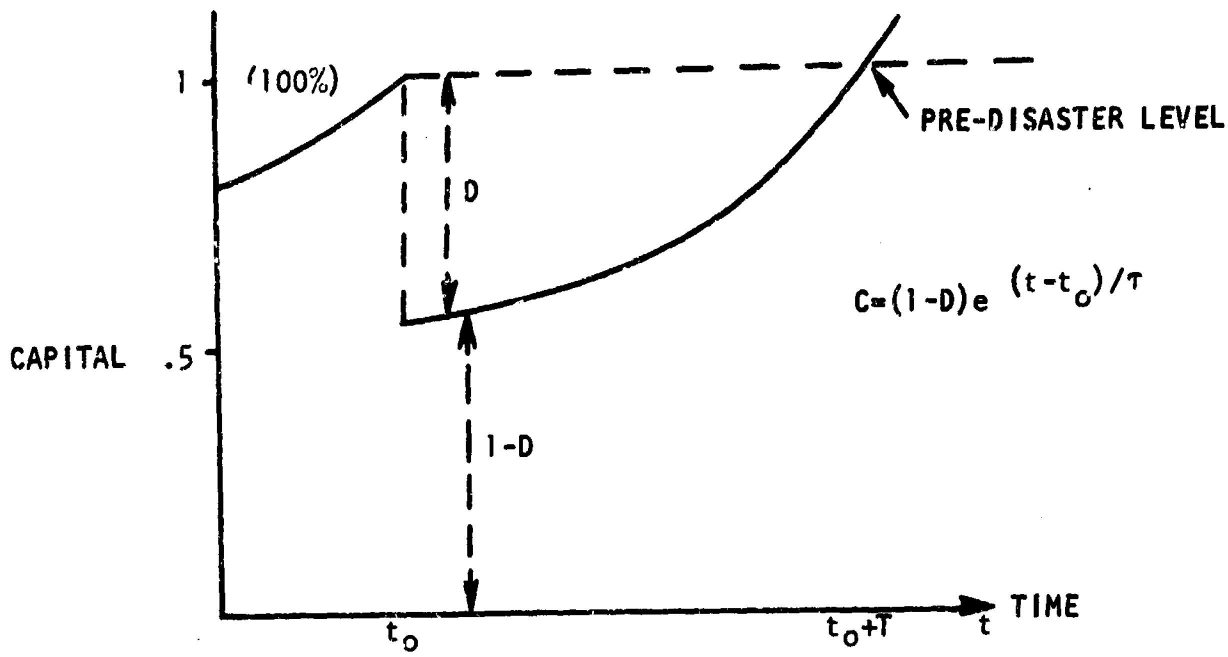
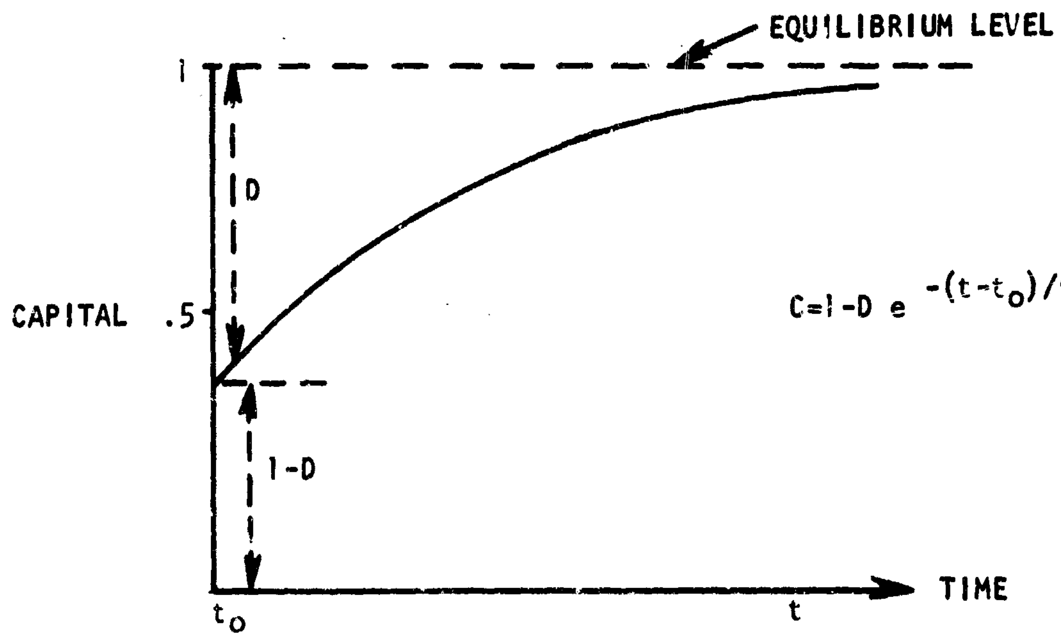


FIGURE 5.2

(ii) ORGANISM GROWTH



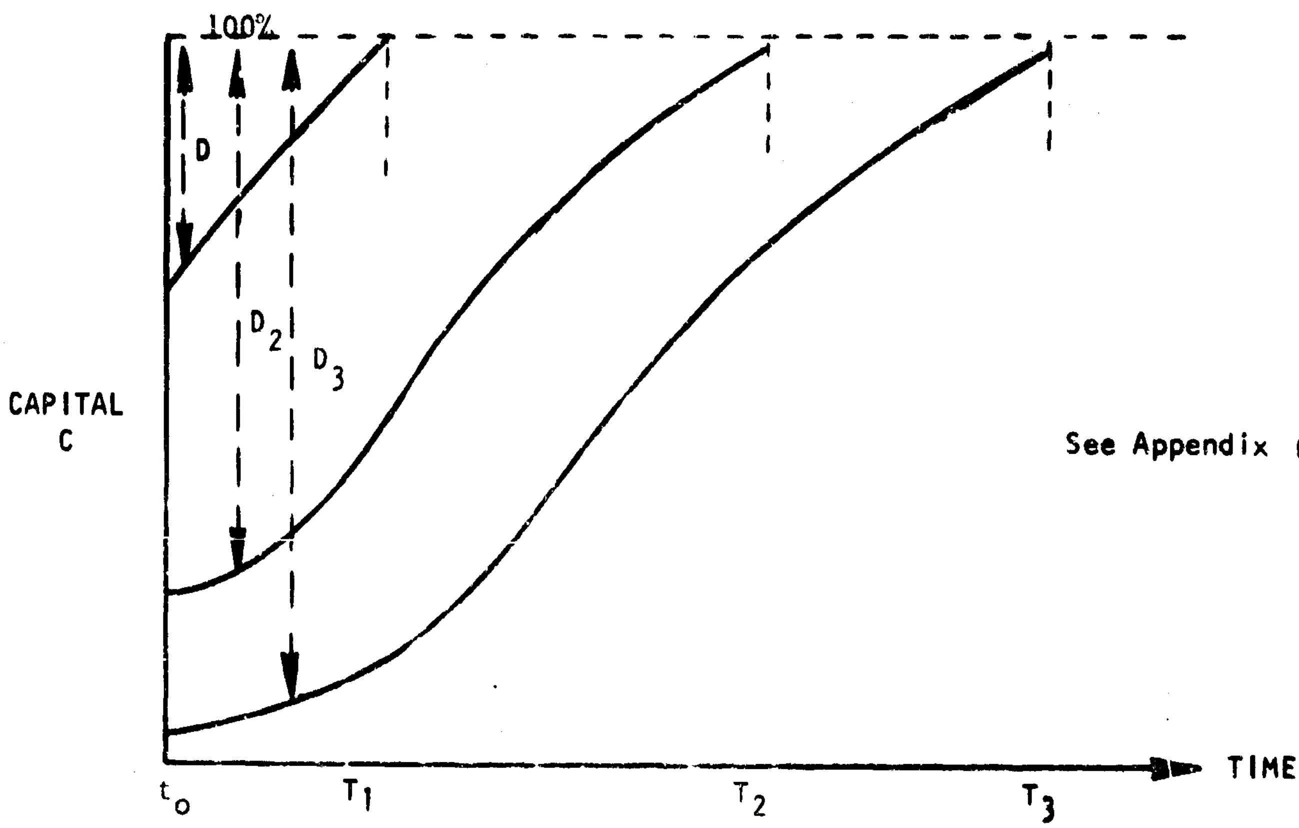
parasitism, predation, starvation, etc.), rather than as a single dynamic constrained by an intrinsic limit.*

We know from experience that economic growth is not particularly well described by (i) except during relatively short periods, and there is correspondingly little reason to believe such a model would describe economic recovery adequately in most circumstances. The model fails to take into account the fact that an economy is highly structured and compartmentalized and is subject to many self-limiting mechanisms, such as requirements for increasingly scarce basic raw materials and energy sources. The highly compartmentalized and structured "network" aspect of the industrial economy seems more [illegible]ent to many analysts than the "compound interest" aspect. (Compartmentalization is, of course, the basic assumption of "input-output" approaches.) To this extent, the second case (ii) might describe the true situation better. Another point of similarity between the actual industrial economy and the self-limiting equilibrium growth model is that recovery and repair mechanisms (including psychological factors) are, in fact, somewhat dependent on the fractional amount of the damage or departure from the preattack "equilibrium." Recent European and Japanese history attests the fact that people often work harder and more efficiently to recover from a setback than they do to secure normal growth. Repair of partially damaged facilities is easier and cheaper than new construction from scratch. Moreover, even reconstruction is easier than new growth because many intangibles such as "memory," skill and knowledge still exist and mistakes, once made, need not be repeated. However, recovery--whether of organisms, ecosystems or economies--appears to be different from self-limiting growth in some important ways. For example, the asymptotic approach to an equilibrium level as illustrated by (ii) is even less characteristic of economic recovery than it is of normal growth. There is a "tailing-off" of growth rate, to be sure, but it is probably attributable to the fact that the high-leverage repair or reconstruction projects tend to be carried out first, as far as possible, and to the fact that a "crisis" level of mobilization (e.g. of labor) cannot be maintained indefinitely once the emergency has passed. People understandably tend to relax their efforts somewhat as normalcy is approached. Analogous behavior can be seen in the case of organisms and ecosystems.

*An example of asymptotic growth might be a population of single cell organisms living in a pond and limited by a shortage of some element, e.g. phosphorus. As dissolved phosphorus became rarer and rarer, it would take longer and longer for a cell to accumulate enough phosphorus to permit it to divide into two.

FIGURE 5.3

(iii) NETWORK MODEL



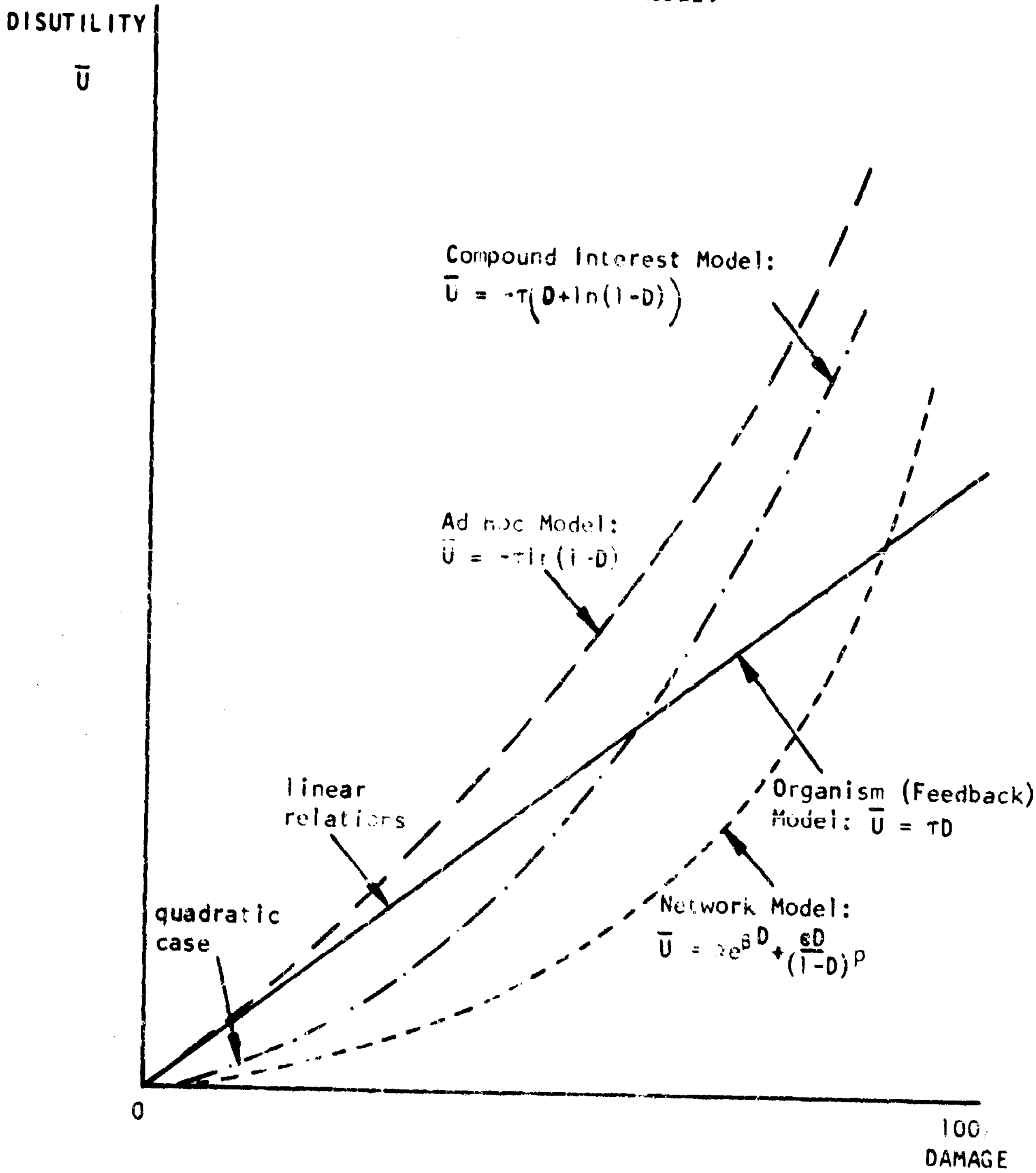
A third approach, which can be given some intuitive justification, is to treat the economy as though it were, in fact, a network consisting simply of junctions and interconnections which can be rank-ordered in terms of multiplicity (or "value"). See Figures 5.3, 5.4, and Appendix G.

As characterized above, the model is highly abstract and, at best, it would be applicable only to certain aspects of an industrial economy. However, a case can be made that the most vulnerable parts of an economy are its distribution networks: electric power transmission lines, water, oil and gas pipelines, roads, railroads and canals. The reason is that damage at a few points can make the whole of such a system inoperative; by the same token, repairing the damaged sections restores the whole. Thus both the disutility of damage (and the utility of repair) are out of proportion to the degree of damage or the cost of the restorations.

The assumption that the junctions are destroyed and subsequently repaired, in order of importance, implies that targeting and recovery policies

FIGURE 5.4

COMPARISON OF RECOVERY MODELS



Derivation of equations for the curves is carried out in Appendix G.

are rational, which may not be the case. Of course, in reality, many targets might be hit more or less simultaneously* rather than in order. Similarly, when it comes to recovery, many repair projects are typically undertaken simultaneously, since there is a limit to the mobility of labor and to the amount of labor which can be usefully employed on a particular job. Despite these constraints, however, we suggest that there is always likely to be a selection of alternative possible uses for surviving resources and that they can be rank-ordered according to economic or political priorities.

The "network" model is evidently a very imperfect description of reality, although possibly more general than it first appears to be. Rather than "junctions" we can speak of alternative uses (i.e. investments) for surviving resources. The major hypothesis, therefore, is that these alternatives can be assigned utilities in a rank-ordered harmonic series. This is suggested, though weakly, by the general applicability of the so-called Yule distribution and the particular relation for cities observed by Zipf. A mathematical analysis of the model is reserved for Appendix G.

We still require operational definitions of "capital" C and damage D. The word "capital" was appropriate for the compound interest model, but is probably inappropriate for the other models, particularly the network repair case. What is clearly meant is productive capability as distinct, for example, from initial investment or (preattack) replacement value. A pipeline broken at one place is as unproductive as no pipeline at all. The value of the undamaged sections is effectively zero unless there is a presumption that repairs will be made and production will resume. This presumption is normally automatic and requires no detailed justification. However, in the aftermath of a large-scale nuclear attack the presumption becomes moot. Even though activity may be intense and rebuilding may be quite rapid, if damage is sufficiently extensive some intrinsically reparable facilities will not actually be repaired. The reason is simply that processes of deterioration and obsolescence continue--the rate may even be abnormally high--and some capital assets which could have been easily repaired if labor and resources were available immediately would have to be much more extensively overhauled or completely replaced if the occasion is long delayed.

In a postattack situation where resources were too limited to undertake all repair or reconstruction projects simultaneously, the preattack balance of values between initial investment and repair costs would be drastically altered. Even substantially undamaged facilities with no immediate prospects of restoration to productive status would lose much of their preattack value, while the cost of repairs could be expected to skyrocket (at least in a free

*Or the enemy strategy might well not be to inflict maximum damage but to demonstrate will, increase risk, or punish a provocation at an appropriate level. Priorities for recovery could still, however, be allocated according to some kind of rank-ordering principle.

market.* Thus, preattack asset value is an unreliable index of postattack value, as has been remarked earlier. For this reason it is preferable to let productive capital, C, be a measure only of actual production of goods and services (GNP).

In hypothetical cases of extremely great damage one must take into account the fact that not all economic activity is potentially applicable to repair and rebuilding. Some portion of GNP, as literally construed, consists of basic goods and services which are (more or less) immediately and locally consumed, i.e. subsistence production. In peasant societies where there is comparatively little commercial activity and little use for money, GNP calculations tend to be unreliable because it is difficult to assign meaningful monetary values, e.g. to food grown and consumed by a family. In a highly developed economy where money is widely used, it is possible to estimate the approximate fraction of over-all effort that goes into such activity, as long as the proportion is sufficiently small that, if the same or equivalent goods and services were bought and sold for money, one could be confident that the price structure would be relatively unaffected. The problem arises when the fraction which is not reflected by monetary transactions becomes large: GNP, in this case, is no longer a well-defined concept.

At the present time, probably of the order of 1% of U.S. GNP consists of goods and services for which money is neither paid nor earned.** After an attack, however, the percentage might rise to substantial levels, particularly in the area of food production and shelter. We need a measure which would be unaffected by such a change, i.e. one which explicitly excludes economic activities devoted to subsistence. Not only would such a measure be less ambiguous than GNP, per se, but it would also come closer to indicating the scope of "surplus" economic activity applicable to recovery and repair:

$$C = \frac{[\text{GNP} - \text{Subsistence}]\ \text{after}}{[\text{GNP} - \text{Subsistence}]\ \text{before}} \cong \frac{[\text{GNP} - \text{Subsistence}]\ \text{after}}{\text{GNP before}}.$$

$$D = 1 - C.$$

There is a new area of potential ambiguity in the definition of subsistence. Clearly, subsistence activities more or less coincide with agriculture, although much agriculture is not in the subsistence category and some subsistence activities are non-agricultural. Moreover, there is

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*This kind of economic situation historically has seemed to favor basic producers and unconventional, uninhibited, middlemen at the expense of traditional end-users and distributors. Typically there is a considerable redistribution of wealth at such times into the hands of "carpet-baggers," "spiv's," or black-marketeers who are in a position to take advantage of the opportunities. It could be argued, of course, that such people perform a useful (even essential) social service.

**Homegrown (and eaten) food; foraging for fish or game; payment in kind for services; barter trade; fuel gathered from forests; crude, home-made shelters; etc. This estimate still excludes some large items such as home improvements, domestic labor by housewives, and the like.

no unanimity--perhaps not even wide agreement--as to what a subsistence standard of living actually entails. We propose to settle the question arbitrarily, if perhaps somewhat unsatisfactorily, by identifying the "subsistence" sector of an economy as the ($) value of agriculture production plus food imports, if any.

There are many phenomena which are not predicted or explained by any simplistic model such as the ones that have been considered here. For example, while social and political factors are hard to assess, it is clear that they will influence the disutility curve. One complication arises from inherent characteristics of the social structure, which is capable of effectively mobilizing resources (in terms of morale, a sense of purpose, etc.) towards recovery from moderate amounts of damage. On the other hand, when the damage is so great that the existing structure is inappropriate to handle the problems, a social reorganization may become necessary for recovery to take place. Such a shake-up will be reflected in terms of redefined objectives and criteria for action and a more appropriate structure. The imposition of price control or rationing might be a low-level example of such a discontinuity. At a higher level of damage, martial law, or "disaster socialism," might be required; at still higher levels, a reversion to local autonomy or even subsistence farming and complete decentralization of authority might be the only means of survival. The details of these conjectures are unimportant here, since they are only intended to illustrate limitations of our models.

As will appear in due course, the economic inputs to this study, especially, have not yet reached a degree of sophistication which would fully justify the effort one would have to expend on a detailed mathematical disutility model (see, however, Appendix G) by permitting us to carry the implied calculations through to the point of comparing the disutilities of various attacks under various postulated assumptions with regard to CD programs, countermeasures and so forth One major point emerges, however, which is worth emphasizing here: to date the importance of the fundamental concept of a non-linear relationship between attack damage and resulting disutility has not been fully appreciated in damage assessment or damage-limiting studies. This point cannot be fully substantiated without taking lengthy quotes from generally classified sources, but people familiar with the relevant documents may recognize the truth of the statement. It is standard practice in all such studies with which we are familiar to calculate trade-offs, e.g. between active and passive defense costs and offense costs, in terms of pre-war dollars. Any such calculation implicitly presumes a linear relation between damage and disutility.[3] In some cases, the assumption even appears explicitly. For example, the 1964 NORAD damage-limiting study assumes that utility is essentially a linear function of surviving population after an initial "threshold." The same study also assumes a purely military criterion for assigning utility, i.e., in terms of contribution to winning the war: this point is worth remembering in connection with our subsequent discussion of the "criteria" problem.[4]

The foregoing remarks about disutility are severely restricted in their applicability by being palpably "one-dimensional." They are meaningful only if one is talking about a specific kind of capital or value, e.g., (total) GNP. In reality, of course, one expects situations where total GNP, population, agricultural production, etc., would all suffer in different proportions and would recover at different rates following an attack. Thus a multi-dimensional definition implies some sort of functional combination of single-dimensional disutilities, i.e.:

$$\bar{U} = A_0 \bar{U}_0 + A_1 \bar{U}_1 + A_2 \bar{U}_2 + \ldots$$

A complete definition would also have to specify the relative weighting factors (or "coefficients") to be assigned to each dimension. The choice depends on personal attitudes about the relative importance of various kinds of damage, as well as assumptions and theories about how recovery depends on various trade-offs. Obviously, different individuals would have different criteria for making choices and would therefore end up with different working definitions for disutility.

Although there is clearly an idiosyncratic aspect to the problem, one cannot abdicate at this point by saying that any choice is as good as any other. On the other hand, one can hardly claim primacy for one's personal choice of criteria for making the necessary choices. It does seem worthwhile, however, to analyze the criteria problem briefly, by taking note of the kinds of intellectual positions which people may have and to see how these might be correlated with other variables.

Among the basic viewpoints, each one of which every person may be thought of as possessing in some degree, are the following:

Attitude Clusters	Criteria for Defining Disutility
Sociological-Psychological	The extent to which "societal" values are preserved. Civil liberties, civil rights, democracy, ethics and morality, etc.
Economic-Demographic	Population, GNP, MVA, capital assets, etc.
Military	The extent to which it is possible to threaten and/or use force in behalf of national objectives--war production, manpower, stockpiles of critical resources, etc.
Nationalist	The extent to which "nationhood" is preserved, territorial integrity, national language, autonomy, sense of nationality or "mission."
Technocratic	The extent to which long-term physical and intellectual resources are preserved: food, energy sources, basic metals, soil, water, etc., also books, machines, specialists, etc.

Personal-Familial-Humanitarian	The extent to which individuals suffer personally or vicariously from pain, illness, deprivation, injury, etc.
Ecological	The extent to which human survival as a biological species is compromised by disturbing the balance of nature.

It is obvious, of course, that these abstractions taken individually do not describe the attitudes of real people. Almost everyone would put at least some weight on every one of these criteria. However, the rank order of importance which various people would assign to them would be radically different. For example, pacifist worker for the American Friends Service Committee might be most concerned about sociological-psychological or humanitarian criteria, and least concerned about military and nationalistic ones (without being unpatriotic). On the other hand, many military officers might reverse the order of priority (without being totalitarian or inhumane). The average businessman or intellectual would probably focus on economic-demographic criteria first, followed perhaps by sociological-psychological or technological criteria.

With relatively few exceptions (e.g. pacifists), most people in the U.S. would assert that none of the criteria are unimportant or should be neglected in choosing a policy. As a justification of this widespread notion that, in some sense, all criteria are equal but one or two are "more equal" than the others, the most likely response would be something along the lines of "if you take care of A, then B, C, D, E and F will take care of themselves." Thus, one man might argue that if the country recovers economically after an attack, we need not worry overmuch about societal values, military weakness, etc. Another will say that as long as the country survives with territory, autonomy, sense of nationhood, and spirit of free enterprise intact, then all the rest will follow.

To the extent that it is necessary to make an explicit choice, ours will be to use economic criteria, while recognizing that other choices exist. Policy decision-makers will, in any case, generate their own criteria on the basis of intelligence, relevant experience, cultural background, religious conviction, intuition and mature judgment rather than analysis.

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1. H. Kahn, On Thermonuclear War, New Jersey: Princeton University Press, 1961, p. 80.

2. "1965 Census of Shareowners" conducted by New York Stock Exchange.

3. See, for example: F. Hoffman, H. Averch, M. Lavin, D. McGarvey & S. Wildhorn, Counterforce and Damage-Limiting Capability in Central War, 1970 (U), R-420-PR, RAND Corporation, Santa Monica, Calif., August 1963, Classified SECRET; or G. Kent, et. al., A Summary of Strategic Offensive and Defensive Forces of the U.S. and U.S.S.R., classified SEC.. .1, prepared for the Director of Defense Research & Engineering, September 8, 1964.

4. North American Air Defense Command, A NORAD Study of Damage-Limiting, Appendix I, fig. I-I (Classified CONFIDENTIAL because of one figure), Colorado, (n.d.).

CHAPTER VI

CONTEXT AND RANGE: EXTREME CASES

1. Perspective

We have made some general and, hopefully, illuminating comments about the relationship between damage and disutility. It remains to be shown, however, how the preceding discussion is applicable to the specific issue of environmental damage.

Theoretically, environmental problems might be considered on their own terms, i.e. one might define disutility in terms of what happens to "the balance of nature" (assuming this could be expressed quantitatively). This approach makes sense roughly to the extent that mankind can be considered as a creature of nature--one among hundreds of thousands of competing life forms--depending on a vast number of delicate interrelationships between occupants of different "niches" in the world ecosystem. It would be particularly appropriate to look at the problem in this way if it could be shown convincingly that ecological upsets might seriously affect the prospects for human survival.

It would be unwise to prejudge this issue, since much of the discussion of environmental problems of nuclear war, to date, have revolved around this area of uncertainty.

On the other hand, to the extent that mankind is independent of his environment--or is capable of modifying it on his own terms--the appropriate criterion of disutility would seem to be an economic one. That is, if man is capable of controlling or manipulating nature to his own ends, then one must focus on the economic costs of doing so in a postattack situation. Ultimately, the discussion must, in this case, revert to a consideration of the influence of environmental damage on a suitable index of economic productivity such as "surplus" GNP.

Ultimately, whether man remains master of his destiny, vis-à-vis nature, after a nuclear war depends on the extent of the damage and disruption. Relevant considerations include the number of (fit) survivors, the amount of property remaining, the extent of the environmental disturbances, what happens in the rest of the world (e.g. Europe), and, finally, social, political and psychological factors.

In turn, these things depend on the kind of war which was fought (who started it, how much warning, how big it was, what the targets were, how the weapons were used, and who won), the relative capabilities of offense and defense on the two sides (especially protection of population and, secondarily, of property), on unpredictable elements such as weather conditions, and on imponderables such as how people feel about the war.

2. Factors outside the Scope of the Study: Some Critical Scenarios

The number of combinations and permutations (alternative scenarios) which would have to be examined to give due consideration to all of the likely variations is clearly very large, even though not all of them are anywhere near equally probable. Moreover, only a few of the alternative scenarios have an important bearing on the prospects for recovery, even in the sense of tipping the balance temporarily one way or the other. It is our judgment that the following hypothetical cases are the most critical (i.e. unfavorable) of the plausible scenarios, assuming a constant given weight of delivered megatons dropped in each war.

1. When war occurs the United States is relatively unprepared, with only a minimal CD program. As a result, civilian casualties and property damage are extremely large. Moreover, postwar recovery is inhibited by confusion and lack of planning. Citizens tend to blame the government for this situation, with serious consequences for postwar morale.

2. The United States strikes first (perhaps to pre-empt an expected Soviet strike) and inflicts unreasonable damage on the Soviet Union but suffers severe retaliation. As a result, the U.S. government is widely blamed for the disaster, both internally and abroad. The population is afflicted with a war-guilt "psychosis" which undermines morale. Public confidence in government plans and programs declines drastically. There is a catastrophic "loss of faith" in the American destiny.*

3. The war does not end quickly, but drags on for several years, with perhaps only occasional exchanges of weapons but continual uncertainty. Repeated alerts and evacuations cause severe economic dislocation. Efforts to rebuild are frustrated by wartime restrictions, fear of subsequent attacks and military priorities. Surplus food is used up.

4. The United States loses its military supremacy as a result of a successful counterforce attack by the Soviet Union.** As a result, Europe is overrun or blackmailed into economic or even political subserviency and the United States is deprived of its allies, most of its foreign investments and trading partners. With a debased currency, essential imports must be paid for in gold or food--which

*There are undoubtedly many scenarios in which the United States might strike first without necessarily producing an extreme guilt-complex in the populace. However, one can imagine circumstances in which it might happen that a U.S. government, pressed for time, perhaps not in possession of all the relevant information, might over-escalate only to learn later that it had made a mistake.

**This looks very unlikely, but it is not impossible, given certain conceivable technological breakthroughs on the part of the Soviet Union, and some sort of unbearable provocation on the part of the United States.

debases the currency further. A disastrous inflationary cycle follows which wrecks the economy (as happened in Germany in the 1920's) and leads to centrifugal politics and burgeoning extremism.

5. The war becomes extremely bitter. The Soviet leadership sees the achievements of 50 years of socialism go down the drain. With a feeling that there is nothing more to lose, prudential calculations seem pointless. Overcome by fury, grief, frustration and pain, they want to punish the United States. They unleash airborne biological agents such as anthrax in large quantities into the midst of an already disorganized population living in temporary fallout shelters and/or refugee camps and with overstrained or primitive medical facilities.

These scenarios are all pessimistic and some are almost too nasty to think clearly about, but it is our business, at this point, to ask how bad things can conceivably get without exceeding the bounds of plausibility. It may well be argued by some people that the usual assumptions--that the United States does not start the war, but wins it, and survives with morale, faith and democracy intact, and that the losing side goes down quietly with, at most, a whimper--are unreasonably optimistic. At any rate, they are assumptions and, as such, subject to re-examination. Details apart, the fundamental point in question here is whether the survivors of a war are likely to have the <u>will</u> to recover, or whether the necessary social and political institutions will survive to make recovery possible.

This is an important uncertainty, nor have we minimized it in the foregoing scenarios. It is impossible to draw ironclad categorical conclusions one way or the other, but the author's opinion can be summarized as follows:

1. Sufficient planning and preparation in advance, or the lack of it, may very likely make a difference of a year or two, or even three, in getting the process of recovery started.

2. Morale factors and institutional failures (such as ungovernable inflation) may also inhibit recovery, possibly by several years.*

3. Sooner or later the survivors will start to dig themselves out of the ruins if they are free to make the attempt. In other words, we believe that there will always be some optimists prepared to invest in the future, no matter how discouraging the past or the present may seem. To argue that social, political or psychological factors <u>alone</u> are capable of preventing recovery permanently seems

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*For what it is worth, the German inflation of the '20's certainly inhibited "real" growth to some extent. On the other hand, German feelings of "war guilt" after World War II did not noticeably affect economic recovery.

tantamount to saying either that no individuals, or only an insignificant number, will ever again try to rebuild a viable society, or that in the face of general discouragement and apathy they could not hope to succeed. This proposition, as stated, is extreme enough to warrant the suggestion that the burden of proof lies on whoever would maintain it. Certainly historical precedents do not support the negative view.

Either way, however, we cannot argue these questions at greater length without digressing too far from the major issue, which is whether man will, or will not, retain a sufficient modicum of control over nature after a nuclear war. Granting that social, political and/or psychological factors will not make a permanent difference--however important their temporary effects may be--the question is seen to depend on the extent of physical damage, and ultimately on the size of the attack. Again, it is useful to try to establish limits, or failing this, to get some feeling for how big "big" is, i.e. how many MT's it takes to do "extreme" damage.

Most attacks which have been "gamed" or analyzed in detail on computers deliver between 1,500 and 5,000 MT's, although a few have been larger (up to 20,000 MT's). The latter would involve something like 2,000 large ICBM's or 400 heavy bombers (or some combination) reaching the CONUS. Such an attack is far beyond currently estimated Soviet delivery capabilities and also beyond currently anticipated capabilities into the 1970's, unless one were also to assume essentially no effective U.S. air defense (against bombers) and no ABM. Moreover, to avoid a disarming counterforce attack in return, the "soft" missiles or bombers would all have to be deployed in secret and launched with greater dispatch and efficiency than is usual for unrehearsed military (or other) operations of comparable magnitude.

For the above, and related reasons, it would seem that with anticipated weapons 20,000 MT's (10,000 fission) is about the upper limit of what can be imagined with any semblance of realism through the '70's, while 2,000 MT's is still a very large attack by 1965 standards and perhaps even by projected 1970 standards.

3. Dominant Physical Damage Mechanisms

To keep the discussion from being open-ended, it is important to try to answer the question: How much physical damage can 20,000 MT's (half fission) create if used in different feasible ways against various classes of targets? To facilitate such a discussion we need to identify the dominating damage mechanisms which are applicable in each case. In some respects, the following table is a summary of the major conclusions of the entire extended study of nuclear weapons effects on the environment which comprises Volume I.

Table 6-1

Dominant Mechanisms

Target	Groundburst	Airburst
Cities	Blast and local fallout followed by (epidemic) disease	Firestorm
Croplands (Crops ---> humans)	β-radiation; Sr-90 contamination	Conflagration
Grasslands (Grass ---> animals,	β-radiation; overgrazing	Conflagration (probably beneficial after one season, however)
Conifer forests and watersheds	Radiation damage from local fallout followed by insect attacks, disease, and secondary fires; some erosion	Conflagration followed by severe erosion and flooding and/or firestorm (?); some erosion
Deciduous and mixed forests	Selective radiation damage	Same as above

If a large enough number of large weapons are groundburst, atmospheric effects would be added to the above.

The radiation hazard from fallout weighs quite unequally on different natural communities. From data compiled and exhibited in Chapter 1, it will be recalled that the acute lethal dose for most coniferous species is under 2,000 roentgens, some such as eastern white pine and pitch pine being as low as a few hundred (Table 1-4). Deciduous species seem to cluster at a higher level, around 10,000 R, while many herbaceous annuals, legumes and grasses range upward to 40,000 or even 60,000 R. Virtually all crop plants, except orchard trees, are in the latter class, as are plants grown or used as pasturage. Table 1-11 summarizes the radiosensitivities of important categories of animals and plants to γ-radiation as presently known.

Closer to ground level, β-activity would contribute more and more to total dose, however, until, at the soil surface, the total lifetime dose--mostly due to β-rays--would be of the order of fifty to a hundred thousand roentgens per KT/mi^2.* Even half this dose would probably be more than

*One would expect large local variations due to "hot spots," surface irregularities, etc. It does not matter greatly for this argument. See Chapter 1, Section 1.

sufficient to kill low-growing plants back to ground level, although roots might well be essentially unharmed. Young shoots and seedlings would also presumably die back as they broke the surface of the soil. On the other hand, full-grown plants with fairly long stems or woody trunks would suffer much less severely from β-radiation. Of course, perennials grow each season from roots and, even if one (or two) years' growth were prevented, the plant cover would probably recover quickly thereafter.

Ground-living insects such as grasshoppers and Mormon crickets would probably not be able to profit as usual from the destruction of the ground cover. In certain stages of growth the fertilized eggs can apparently be killed by a few hundred roentgens. Sterilization of adults requires as little as 350 R (Chapter I, Section 4). If grasslands receive an average long-term β-dose of 1,000 R (corresponding to the order of $\sim$50 R from γ's) or $\sim$.01 KT/mi^2 fission products, the grasshopper population would presumably be virtually eliminated for some years.*

If grasslands and pastures were attacked radiologically, as above, and if plants are in fact as susceptible to β-radiation as we have assumed, the 1,050,000 square miles of grasslands in the United States would be severely damaged by 0.5 KT/mi^2 or 525 MT's of fission products spread evenly. On the same basis, the 615,000 square miles of cultivated crops would be put out of production for at least a year by an additional 300 MT's--again spread evenly. (To allow for unevenness and overlapping of fallout patterns, the total number of MT's delivered as bombs required to get at least 1 KT/mi^2 over a large area is considerably larger. The multiplier Q_R, defined in Chapter I, is introduced to relate idealized uniform fallout patterns to realistic ones.) Even if rangelands were spared direct damage, but cultivated farm lands were heavily attacked, an intolerable strain might be put on some grazing areas. Economic motivation to force the land to support the largest possible number of meat animals, regardless of long-term risk to soil, might be hard to resist. Under such circumstances, moreover, grasshoppers and Mormon crickets would certainly thrive and help compound the problem. Drier than average weather (such as occurs naturally every few years) would denude the land and bring on dust storms reminiscent of the 1930's. On the other hand, if several years of exceptionally good rainfall came along at the right time, the emergency might be surmounted with only minor damage.

The disutility of an attack which seriously inhibited agriculture for a year or more would depend strongly on the amount of stored surplus food available to feed the population and, secondarily, on whether a substantial number of domestic animals could be kept alive for the requisite period. Whether the ultimate outcome was a great disaster or merely an economic setback would depend on a number of rather complex preattack and postattack issues which will be discussed in the next chapter.

*The species would undoubtedly survive in a few "clear" areas and reconstitute itself afterwards over a period of a few ($\sim$ 5-10) years. Also, eggs of some species can remain dormant underground (where they may be somewhat protected from β-radiation) for several years.

A radiological attack on farm and grazing lands would have another serious consequence, namely, high-level Sr-90 contamination. Some relevant calculations appeared in Chapter I, Sections 1 and 6. To recapitulate, Sr-90 is chemically similar to calcium and follows calcium through the various metabolic processes of living organisms. It enters the diet via three basic routes:

plants---> cows---> milk
plants---> animals---> meat
plant products consumed directly

Because of the large amount of calcium in milk, it is currently a major source of dietary Sr-90. Techniques of inexpensively removing the radiostrontium have been developed, however, and will be discussed later. On the other hand, relatively little Sr-90 is found in meat, mainly because there is so little calcium in muscle tissue. Plant products consumed directly, especially those rich in calcium such as green vegetables, are the other major source of dietary Sr-90.

An important factor, which suggests several countermeasure possibilities, is the fact that calcium is somewhat preferred over strontium in virtually every life process. Thus, every time calcium and strontium together are metabolized by a plant or animal (or even an individual organ such as the digestive system or the mammary gland), some of the strontium is eliminated and excreted. The more such "filtering" processes there are, the greater the biological discrimination against Sr-90. Hence, the <u>ratio</u> of Sr-90 to calcium in milk is smaller than the ratio in plant foods (which, in turn, is smaller than that in the soil). This is a fortunate accident of chemistry.* It also has important implications for postattack agricultural priorities, specifi-
1, cally suggesting a strong emphasis on meat production. One awkward postattack dilemma that one can foresee in this connection is the possibility of a shortage of Calories, in the short run, inducing farmers either to overgraze surviving pasturage or to slaughter animals rather than feed them. The implication of these questions will be analyzed later.

The calculations and estimates previously referred to (Chapter I, Sections 1 and 6) suggest that land contaminated with fission products at the rate of a few KT/mi^2 might result in a very high cancer risk for infants fed on plant foods grown thereon. The addition of an extra link in the food chain, i.e. animals, would reduce the Sr-90 hazard (e.g. in milk) by a factor of 2-4 (while also reducing the Calorie production from the land by 50-80%). Allowing for the possibility of artificially removing 90-95% of the Sr-90 from milk, an over-all reduction of 95-99% would result. Thus, grazing land, or land devoted to crops to be fed to animals, could take 20-80 times more fallout for a given (e.g. 10%) cancer risk.

The twin threats of interdiction of agriculture--directly by β-radiation from fallout or indirectly through Sr-90 contamination of food grown

*As Herman Kahn has pointed out, in the absence of specific data one might equally well have expected things to go the other way (as happens in the case of Cs-137), which could have made the problem some 100 times worse than it is actually.[1] Nevertheless, it is still fairly bad.

on the land--can be ameliorated to different degrees by preattack or post-attack countermeasures. Again, the discussion of details will be reserved except for the remark that, of the two mentioned, the more serious threat is likely to be the Sr-90 problem, which is harder to counter. In any case, such an evaluation will be highly conditional. With this caveat firmly in mind, we take $D_E = 0.5$ KT/mi^2 tentatively as the critical* damage figure for both cultivated and grazing lands, since Table I-11 suggests standing crops of the major food plants would receive lethal γ-doses at .2-.6 KT/mi^2.

In the case of coniferous forest biomes, the basis for the calculations turns out to be quite different, although the results are similar. As far as one can tell on the basis of admittedly scanty experimental data, most fallout particles would end up on the bark or on the ground, rather than sticking directly to the highly sensitive twigs and buds. If this is correct, the major initial hazard would be from γ-emitters. Note that if about 5% of the fallout particles remained for only a few weeks within range of the sensitive growing-points (meristems) of the trees, the resultant β-dose would roughly equal the total γ-dose from fallout on the ground. However, since only particles quite close to the meristems would "count," because of the short range of β-particles, we conjecture that the contribution of the β's is nevertheless less than that of the γ's. Table I-11 suggests a choice of $D_E = 0.06$ KT/mi^2.

Taking into account the predicted distribution of lethal doses and secondary effects such as fires, attacks by bark beetles, etc., to which evergreens are particularly prone, one is inclined to estimate that an evenly spread dose of .03 KT/mi^2 fission product corresponding to an integrated dose of 600 R would be almost certain to kill any conifer forest, and as little as .01 KT/mi^2 <u>might</u> be enough to trigger a sequence of synergistic insults which would ultimately lead to the same result. See Appendix D of Volume I. We take $D_E = .03$ KT/mi^2 as a moderately conservative estimate of the critical level.

By contrast, deciduous forests are apparently much less vulnerable. Radiosensitivities cluster around a range which is about an order of magnitude higher than for conifers. Furthermore, deciduous forests, being mixed, are certainly somewhat less subject to secondary attacks. Altogether, a factor of 20 difference seems not unlikely. For simplicity we take $D_E = 0.5$ KT/mi^2.

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*By "critical," we do not necessarily imply a discontinuity, or even necessarily a perceptible "knee," in the dose-response curve. The meaning is more nearly that, at .1 KT/mi^2, one suspects the problems are not really difficult to solve, while at 3 KT/mi^2 they are probably insuperable. Crudely, one feels that .5 KT/mi^2 marks the transition region.

lost. In many cases crops would already have been harvested, would not yet have been planted, or could still be replanted; only for a few weeks just before harvest would fire cause serious damage. On many potential rangelands fire would be a positive benefit by destroying woody shrubs such as sagebrush and mesquite, thus allowing grass to return the next year. As the fire weather data in Chapter II indicates, these are precisely the regions where critical fire weather is most likely.

Using the simple rule of thumb derived in Chapter II,

$$\text{Area} = \pi R^2 + \alpha(2 + \frac{\pi}{2})R$$

where R is the ignition radius and α the coefficient of spread (Table 2-6), the fire hazard can be estimated crudely by neglecting the firespread term. Assume 200 10-MT weapons are exploded over the watersheds and agricultural areas of the U.S. in summer. According to Figure 2.4, the average annual per cent of opaque cloudiness for important agricultural areas (except in the irrigated areas of the Southwest and California) would be about 40% while for major watersheds the figure would be around 55%. We assume the fraction of a region under cloud at a given time is equal to the time average at a given point, and suppose that there are two kinds of days, "cloudy" and "fair." The average ignition radius for a 10-MT airburst on a "cloudy" day is about 7 miles and on a "fair" day is 18 miles. Thus for agricultural areas the average area ignited per weapon is:

$$[.60]18^2\pi + [.40]7^2\pi + \cong 670 \text{ mi}^2$$

while in watersheds

$$[.45]18^2\pi + [.55]7^2\pi + \cong 450 \text{ mi}^2$$

If equal numbers of weapons were allocated to each type of area a total of 120,000 square miles might burn. If watersheds alone were attacked the area affected would be slightly smaller, although the damage would be more severe.

Allowing for the possibility that the attacker might choose his time and optimize in other ways, it is clear that something like a quarter of U.S. forests might be hostage to such an attack. If some of the fires should develop into firestorms rather than conflagrations, the chances are that something less than the indicated 120,000 square miles would actually burn--possibly 90,000 square miles or so. Many fires at or near the perimeter would go out or burn back toward the center under the influence of radially converging winds. The long-term damage in this case would be the more serious, however, because the scaling law for reseeding and repopulating the devastated areas suggests that recovery time increases in proportion to an exponential function of the radius of the area (see Chapter IV, Section 6). Contrary to the case of a conflagration, one would not expect refugia, from which repopulation could start, to survive inside a firestorm perimeter.

Incidentally, a large number of smaller weapons would cause ignition over a wider area and would increase the fractional firespread hazard as well. On the other hand, the scaling law for recovery from firestorms is such that if large-scale firestorms should develop the worst damage for a given number of MT's [illegible]ably involves the largest possible individual weapons (i.e. 20 100-MT bombs would be worse in the long run than 200 10-MT bombs). This is an interesting point.

We note also that over half of the CONUS could be covered by a 20,000-MT attack consisting of 2,000 10-MT optimized airburst weapons, so that if typical burning conditions prevailed and targeting were optimized in terms of local weather patterns, a substantial fraction of the country would burn. Probably 10,000 1-MT weapons would have a similar consequence.

Secondary effects following firestorms on forested watersheds could be important. Assuming that recovery of the burn-over upstream areas is long delayed because of the scale effect noted above, one would expect maximum local surface runoff rates to be increased by a factor of as much as 4 or 5 right from the start, and catastrophic erosion to occur within three or four years. Coming on top of a flood control situation which is already marginally unstable,* one can hardly avoid the conclusion that spectacular upstream spring floods would occur in some of the years following the attack--almost certainly beyond any hope of controlling by any extension of normal means--possibly in combination with unusually low water levels during the remainder of the year. Hence, in addition to the several hundred thousand square miles of watershed destroyed, the chances are that much of the 150,000 square miles currently considered floodable (Chapter IV, Section 7) would be repeatedly flooded in later years, and some would be permanently damaged by deposition of thick layers of infertile subsoil washed down from burned-over hillsides upstream. Waterfronts of a number of river cities (e.g. St. Paul, Pittsburgh, St. Louis, Memphis, Cincinnati, Louisville, Evansville, New Orleans, and Sacramento) might also become virtually untenable because of flood threats. The value of the potentially floodable areas is out of proportion to the number of square miles involved. For example, much of California's rich Central Valley, the productive cotton and rice fields adjacent to the lower Mississippi, and the potato farms on the banks of the St. John's River in Maine, might all be lost to agriculture at least temporarily.

Agriculture in adjacent areas not flooded would also suffer as a result of lowered water tables, due to the greater percentage of storm runoff. It is difficult to estimate the degree of importance to be attached to this effect, although it should clearly not be ignored. Crop yields reduced by factors of 50% would not seem at all unlikely in some areas of low summer rainfall.

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*Consider the 1965 Mississippi River floods!

4. Counter-Environment Attack

The following two tables summarize the arguments which have been presented at length in the foregoing.

Table 6-2

Extreme Damage Criteria*

Target Biome	Radiological Effective Density D_E KT/mi^2	Thermal Effective Density D_E KT/mi^2
Cultivated Land	.5	0.25
Grasslands & Pastures	.5	0.25
Conifer Forests	.03	0.25
Deciduous Forests	.5	0.25

Table 6-3

Environmental Attack (Preliminary)

Target Biome	Area (mi^2)	Total Weight (MT)
Cultivated Land	615,000	615
Grasslands & Pasture	1,050,000	1050
Conifer Forests	540,000	270
Deciduous Forests (and mixed)	420,000	4200

(Total weights 615, 1050, 270, 4200: $\times\ Q_R S_R$ or $Q_T S_T$)

The inefficiencies Q_R, S_R, Q_T, S_T must now be estimated for each of the four major biomes. As regards the first of these parameters, we note that the effective density D_E (in KT/mi^2) over an area would be equivalent to the total density D divided by Q_R or, in other words, the value of D required to achieve an effective density of D_E (fission KT/mi^2) is just $D = Q_R D_E$. For the two cases of primary interest, $D_E = .03$ and $D_E = 0.5$, one obtains by crude extrapolation from Figure 6-1 the values shown, equating $L = 3{,}000$ with $D_E = .15$ KT/mi^2.

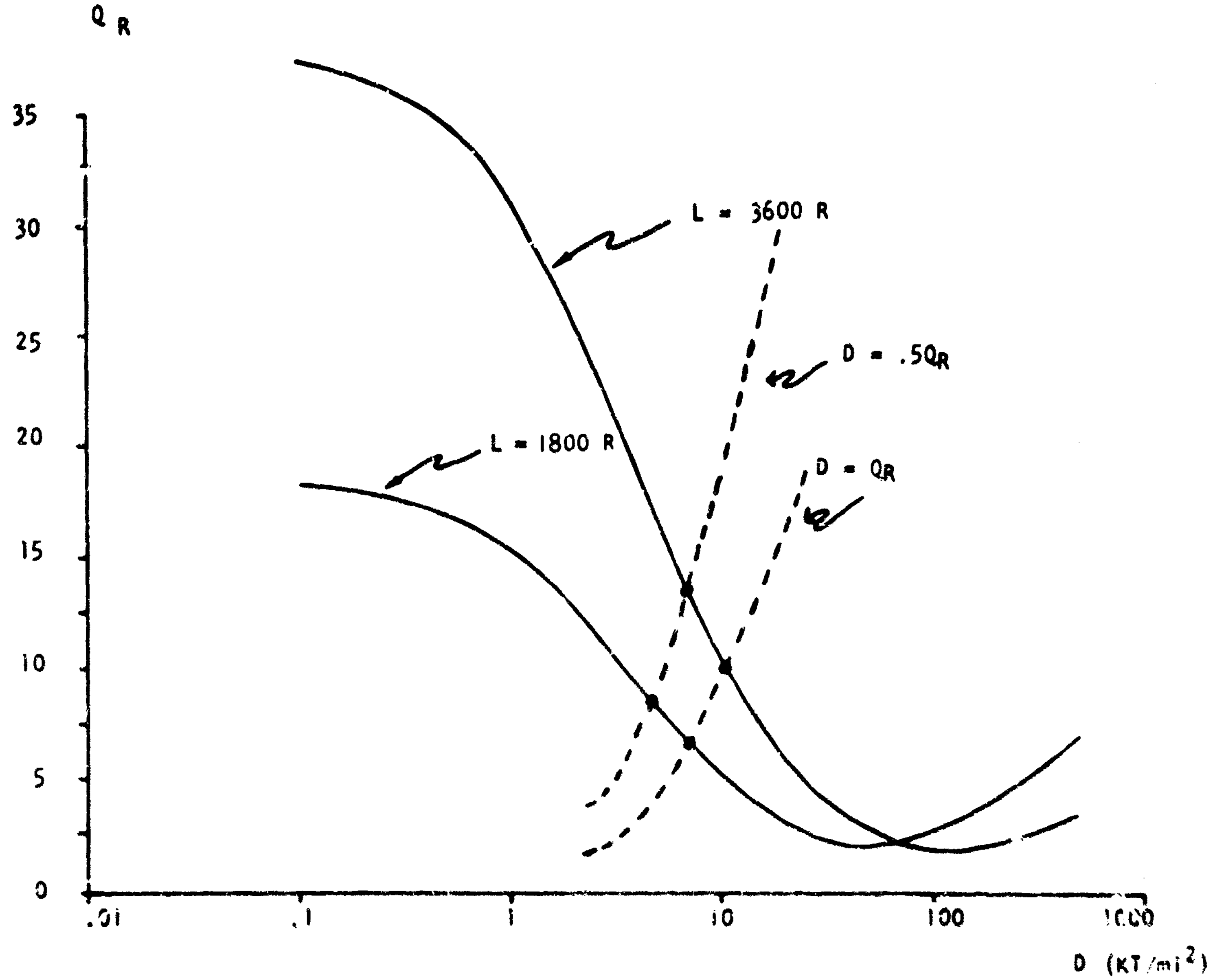
$$D_E = .03 \qquad Q_R \approx 10$$

$$D_E = 0.5 \qquad Q_R \approx 25$$

*In comparing the two columns it must be kept in mind that KT in the radiological effects column refers to fission products only.

FIGURE 6.1

RATIO OF TOTAL TO "EFFECTIVE" MT's FOR RANDOM ATTACKS OVER LARGE AREAS



The radiation shielding inefficiency S_R discussed in Chapter I, Section I is probably of the order of 3 or 4 in forests (where γ-radiation is important), but would not be much greater than unity for rangelands and croplands for which β-radiation is crucial.

For thermal effects the over-all ignition inefficiency was estimated in Chapter II to be

$$Q_T \cong 33,$$

while the shielding inefficiency, which takes into account atmospheric attenuation due to clouds, smoke and dust, may take any of a wide range of values depending on weather, e.g.:

$S_T = 1$ for an average-clear day* (by definition)

$S_T \cong 10$ for medium cloud

$S_T \cong 100$ for very dense cloud or heavy fog

On a very exceptional day one might find most of the country under clear skies, although on the average (as pointed out in Chapter II) roughly two-thirds of the country would probably be under some kind of cloud cover. Since we are considering fairly extreme cases, however, let us assume $S_T = 1$ for grasslands and pastures and $S_T = 2$ elsewhere. Summarizing, then:

Table 6-4

Extreme Environmental Attack

Target Biome	Area (mi^2)	Radiological $Q_R S_R D_E$	Radiological Weight (MT) Fission	Thermal $Q_T S_T D_E$	Thermal Weight (MT)
Cultivated Land	615,000	~ 13	~ 8,000	16	~ 10,000
Grasslands & Pasture	1,050,000	~ 13	~ 13,000	8	~ 8,700
Conifer Forests	540,000	~ 1	~ 540	16	~ 9,000
Deciduous Forests	420,000	~ 50	~ 21,000	16	~ 7,000

Since the column for radiological attacks refers to fission MT's only, 50% fusion weapons would require doubling the numbers. Apparently in very clear weather the thermal hazard is greater than the radiological hazard since fewer MT's would be required to achieve extreme damage. However on a more typical day in which much of the CONUS was under some cloud cover, the situation would probably be reversed and the radiological hazard would be the greater.

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*Evidently on an ultra-clear day the shielding inefficiency might be less than unity. However such days are very rare.

As has been pointed out previously, the various estimates contain many uncertainties and could easily be off by a large factor. In particular, the problem of synergistic potentiation of multiple stresses may have been inadequately taken into account (See Appendix D).

The disutility of what we have labeled "critical damage" varies considerably from one target biome to the other, and from one type of damage to another. In the case of cultivated lands, for instance, the disutility of a high level of destruction would be relatively small if the country could survive on stockpiled food for one growing season. On the other hand, without such stockpiles the situation could be disastrous. As regards pastures and grazing lands, much would depend on the survival of the animals, and, as above, the availability of stockpiles of feed. If a reasonable fraction of the herds were saved and could be fed on stockpiled grain, as might easily be the case in the event of a thermal attack,* the long-term effect of fires on the pasturage might even be ecologically beneficial in some areas. On the other hand if the animals were killed by the attack, or they starve or are killed and eaten thereafter, the immediate recovery of the grasslands themselves would have no practical significance. As regards forests, their destruction by fire would hasten erosion of watersheds, floods and silting. Compared with other problems facing the postattack society these might be relatively tolerable. If the forests were killed by radiation, however, the ground litter would be undisturbed (unless destroyed by secondary fires) and would probably protect the soil until a new crop of vegetation became established. In either case, much of the standing dead timber could still be harvested and utilized. The real economic loss would be deferred to later years, as salvageable dead trees were used up before a new crop of saplings reached maturity.

Very roughly, one would expect the fraction of a target biome subject to complete destruction to scale linearly with the weight of attack, for attacks smaller than the ones described in Table 6-4. Thus 1000 MT's airburst on an "average clear day" would presumably "destroy" something like 10% of the cultivated land in the CONUS. Unless this level of direct physical damage were enormously compounded by social, economic or political factors, e.g. a breakdown in the farming "system," it is hard to see why environmental recovery should not take place. Moreover, apart from hypothetical situations where lost agricultural productivity results in extreme famine, the appropriate question seems to be, not whether survival (and eventual recovery) are possible, but how expensive it would be in terms of the postattack economy.

References

1. Herman Kahn, On Thermonuclear War, Princeton, 1961, p. 20.

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*A herd of cattle or sheep would not be highly vulnerable to thermal flash, since thick hides and hair protect the body and, to some extent, they would tend to shield each other.

CHAPTER VII

ENVIRONMENTAL-ECONOMIC CONSIDERATIONS

1. Framework

Insofar as the many partial arguments which have been exhibited in previous chapters can be said to imply any conclusion, it is that nuclear wars of a few thousand MT's, enough to destroy most cities and kill a large percentage of the (unprotected) population, would not cause a comparable degree of damage to the environment. The analogies and arguments which have been alluded to, in the past, in support of a predicted ecological "catastrophe" (recall some examples in the Introduction) are not sufficiently compelling in terms of what is presently known--whatever the abstract but unknowable truth may be--to justify concentrating most of our attention on such a contingency. Even for "large" hypothetical wars of 10,000 MT's (fission) or so, we would argue that the outcome depends mostly on how effectively postattack problems are handled as they arise. For large wars, admittedly, the margin for maneuver may be smaller and the disutility of an error or miscalculation may be greater. For instance, some of the political-social-psychological factors mentioned at the outset of the last chapter could conceivably be crucial, e.g., if demoralization or social chaos resulted in a two-year delay in reorganization.

In this chapter we shall attempt to focus (somewhat unsystematically) on the projected environmental-economic disutilities of hypothetical nuclear attacks under assumptions ranging from:

(1) no preattack preparations,
(2) preattack preparations such as might be accomplished during a period of tension,
(3) extensive peacetime preattack preparations.

The third case looks rather unlikely at the moment, but should U.S.-Soviet relations return to the "Cold War" level of tension, one might imagine fairly substantial CD programs being carried out over a period of years. Increased CD spending would also presumably accompany any expanded active defense effort such as Nike-X.

The measure of disutility developed in Chapter V which seemed most appropriate (or, at any rate, least inappropriate) was total GNP minus the fraction required for subsistence or surplus GNP.* As far as possible we shall try to examine costs in this light: a program costing .1 postattack SGNP's is "expensive," no matter how big the postattack SGNP is in terms of preattack dollars. A program costing .001 or even .01 postattack SNGP's might be described as "cheap" to "moderate" unless SGNP becomes very small.

*Shortened to SGNP in the following.

The fraction of GNP per capita devoted to subsistence in a postattack world would almost certainly increase both as a result of disproportionate destruction of cities and productive capacity, and because of postattack economic disequilibrium due to "bottlenecks" in certain key industries. Moreover, the postattack demand pattern during the reconstruction period would be likely to change with respect to the preattack situation, e.g., more stress on building materials and industrial goods, less on consumer goods and services. To the extent that production could be shifted from one sector into another, the problem of imbalance might be somewhat alleviated in time, but the chances are that a substantial part of surviving industrial capacity would be temporarily under-utilized and would meanwhile not contribute to SGNP.

The relative cost of subsistence production--primarily food--might also change sharply as a result of the war. On the one hand, the postattack diet need not be as rich, varied, or conveniently prepackaged as the preattack one. There is considerable "slack" in the system which could be taken up. Moreover, the number of survivors who must be fed would be smaller than the preattack population (depending strongly on the effectiveness of the CD program in effect at the time of the attack, however). On the other hand, some land would be out of production, at least temporarily, either because of contamination, destruction of equipment and facilities, or isolation from markets and sources of supply. Food processing and distribution might be haphazard--hence inefficient and expensive--for a time. Decontamination to mitigate the Sr-90 or I-131 hazards would add to the cost of some foods. Productivity per acre might be reduced due to the necessity to abandon fertile land due to contamination, erosion or silting; or because of shortages of fuel, electric power, fertilizers, pesticides, and high-quality commercial seed. Food might have to be imported, adding to transportation and balance-of-payment problems. Finally, an increased economic incentive to stress meat production, on account of the Sr-90 hazard, would be costly in terms of inefficient utilization of available Calories.

In classical economic theory the dollar price of a good depends on the balance (at the margin) between supply and demand, while demand varies with relative prices, assuming other factors can be ignored to a first approximation. The "supply curve," which expresses the fact that the first units of supply must fill the most urgent demands, and therefore command the highest prices, is a function which is presumed to exist and to describe this complex interrelation. Similarly, supply (the amount produced) is a function of the cost of production. Thus, if demand for a commodity, such as a food, is low, only the cheapest sources need be exploited, resulting in low prices. At a high level of demand, on the other hand, expensive sources may have to be utilized, e.g., marginal farmlands requiring expensive fertilizers but with low yields, and prices will rise correspondingly. At a high enough demand level it might even be economic to synthesize food elements, such as amino acids, artificially from basic chemicals. (At current demand levels the price of a synthetic diet seems to be about $12 per person per day.) The extent to which classical economics is strictly valid in the present context is, of course, open to serious question. However,

it is hard to find any examples of cases where the operation of these economic mechanisms has been circumvented successfully, for any length of time, e.g., by exhortation or by governmental controls.

Figure 7.1, which is "derived" somewhat crudely in Appendix H, shows schematically what might be expected. Changes in total GNP, which might for convenience be indexed in terms of preattack dollars, would effectively shift the productivity curve to the right, and possibly change its slope as well. Decreased demand, from a smaller postattack population willing to accept a more austere diet, would push the operating point down and toward the left; but increased direct costs of food production and distribution, decontamination and, possibly, emphasis on meat, would push the point back up and to the right.

It is premature to attempt to carry through the indicated calculations explicitly, even for a specific hypothetical war, partly because of the number and crudeness of the approximations which would obviously have to be used along the way, but mainly because the economic interactions are clearly central and require much more study and elucidation. Among other things, a better model for the functional relationship between agricultural productivity and investment (i.e., the curve in Figure 7.1) is needed.* Since the first variable is not a simple function of the second, it is clear that any such model has extremely limited validity at best, and is easily subject to abuse and misinterpretation. A second, and more fundamental, need is for a usable model to describe the functional relationship between physical damage and economic damage (reduced GNP). To date, the closest approach to this discussed in the open literature seems to be Winter's study for RAND Corp.[2]

2. Agricultural Problems Associated with Two Prototype Attacks

It is worthwhile attempting, however inadequately, to pull together some of the fragmentary calculations which have been made heretofore. This means making some assumptions about the weapons, the targeting, season of the year, etc., and then analyzing the probable level of damage, the postattack agricultural production, and the prospects for ultimate recovery--in the context of each of the three alternative assumptions about CD programs and plans.

a. Thermal Attack

Weight: 20,000 MT's (10,000 MT fission equivalent)

Season: July, August or September**

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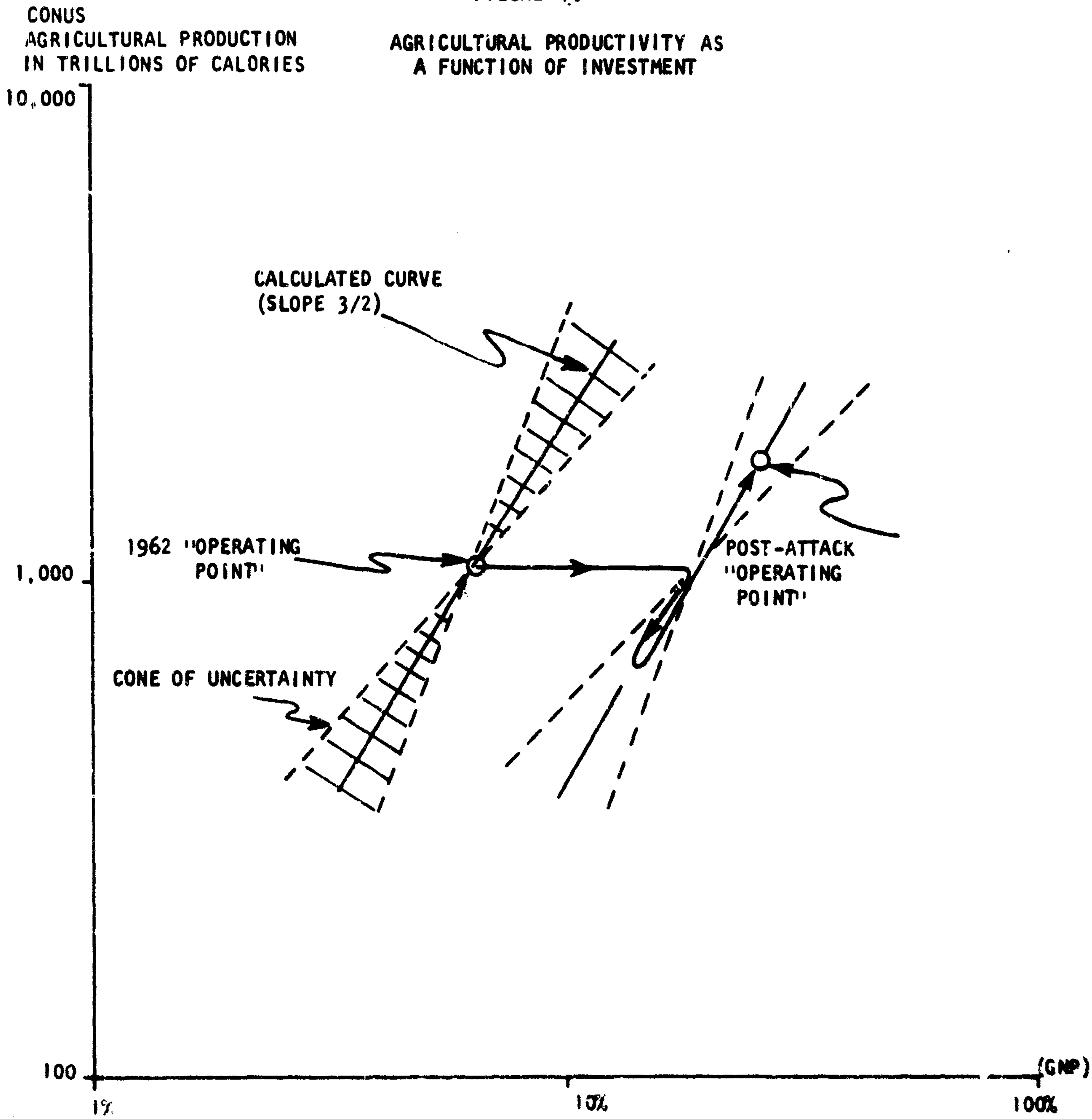
*S.R.I. has developed a rather detailed input-output model for agriculture, some of whose structural features were borrowed in Appendix H.[1] However, existing approaches rely too heavily on considerations valid only at the margin.

**These months are (a) the driest, and (b) span the harvest season. They would be the most tempting for a thermal attack.

FIGURE 7.1

AGRICULTURAL PRODUCTIVITY AS A FUNCTION OF INVESTMENT



Targets: Mixed counterforce plus counter-environment, including all major irrigated areas such as Imperial Valley, California; the major corn-belt and wheat-belt areas; and critical watersheds such as the western slopes of the High Sierras, western slopes of the Appalachians and the northern Rockies.

Such an attack could destroy a large fraction (~ 50-75%) of standing crops, hay (including haystacks) and many farm buildings; it could also cause severe damage in some critical forested watersheds resulting in early melting, erosion, exceptional runoff, and quite possibly flooding, especially in the Mississippi basin, the Columbia basin and in the Central Valley of California.

In addition to unharvested standing crops, a substantial fraction of the harvested grain being stored on farms, or in silos and elevators, might also burn as a result of conflagrations in towns and cities throughout the target area and in neighboring parts of Canada. The extent of such destruction would depend on the details of targeting and on how fireproof the elevators are. This could be a critical vulnerability, but it is not within the scope of the present study. The degree of concentration of grain storage facilities is indicated by Table 7-1.[3]

Since the weapons were assumed to be mostly airburst, to maximize blast and thermal effects, relatively little fallout would be involved. Therefore, in comparison with other problems, Sr-90 contamination would not be severe, and the population could safely rely on a grain diet (suitably supplemented) for a while. The destruction of most of one year's standing crops and, perhaps, 50% of the stored surplus grain would still leave enough grain and other food in storage to feed the population until the next season, even if cities were spared and casualties were low.* Mortality among (surviving) farm animals and dairy herds would probably be extremely high, however, with the winter feed and forage crops destroyed. Many might have to be slaughtered in the winter, temporarily increasing the fresh meat supply, but at a severe cost in terms of reduced breeding stock for subsequent years. In all likelihood this would be one of the major long-term agricultural-economic effects of the war. Another would be the degradation, due to flooding and silting, of some low-lying river valley farmlands. Finally, the surviving population would be restricted to a (relatively) vegetarian diet for several years, even though "normal" farming could probably be resumed almost immediately in most areas if the organizational and economic prerequisites exist.

Note that we have described a case in which economic recovery is presumed to be possible and to take place in a fairly orderly fashion, despite the magnitude of the attack. However, the favorable outcome is not guaranteed. For example, if 75% of the stored grain were destroyed (instead

*Winter wheat would be available within 6 to 8 months, assuming it could be planted after the disaster.

Table 7-1

Grain Elevator Capacities in Various Cities

Cities	Capacity (Bushels)
Minneapolis, Minnesota	129,580,000
Kansas City, Missouri	112,628,000
Ft. William & Port Arthur, Canada	101,921,000
Fort Worth, Texas	101,559,000
Wichita, Kansas	89,054,000
Chicago, Illinois	85,902,000
Duluth & Superior, Minnesota	69,400,000
Enid, Oklahoma	67,062,000
Portland, Oregon & Columbia River	58,126,000
Salina, Texas	58,000,000
Lubbock, Texas	57,919,000
Buffalo, New York	51,915,000
Hutchinson, Kansas	50,963,000
Lincoln, Nebraska	50,604,000
Toledo, Ohio	39,650,000
Council Bluffs, Iowa	35,724,000
St. Louis, Missouri	31,548,500
Milwaukee, Wisconsin	30,190,000
St. Joseph, Missouri	27,895,000
Amarillo, Texas	27,500,000
Seattle & Tacoma, Washington	26,940,000
Indianapolis, Indiana	22,300,000
Vancouver, Canada	21,806,500
San Francisco & Bay Region	21,147,000
Oklahoma City, Oklahoma	19,688,000
Decatur, Illinois	19,000,000
Montreal, Canada	17,512,000
Des Moines, Iowa	14,525,000
Dallas, Texas	14,300,000
Sioux City, Iowa	13,756,000
Albany, New York	13,500,000
New Orleans, Louisiana	13,000,000
Midland, Michigan	12,816,000
Baltimore, Maryland	12,600,000
Memphis, Tennessee	12,000,000
Baie Comeau, Canada	11,868,000
SUBTOTAL:	1,543,899,000

of 50%), to avoid widespread malnutrition or even mass starvation it might be necessary to import food and, in later years, livestock on a large scale. This, in turn, depends on the survival of port facilities, transportation, foreign suppliers and some source of foreign exchange. In the first year it might be very hard to meet all of these requirements. Port facilities, in particular, are extremely vulnerable; practically all existing facilities in the CONUS could be destroyed by a hundred MT's or so, appropriately distributed. One possibility for obtaining foreign exchange is that surviving U.S. consumer-goods industry might find export markets to replace the internal market, but this would be fraught with difficulties at best, and would probably be impossible without active and substantial government cooperation. The prewar U.S. advantages of concentrated capital resources, superior technology, automation and propinquity to a large homogeneous domestic market would very likely be lost or diminished and manufacturers would have to cope, at the very least, with shortages of all sorts, uncertain transportation, probably exchange controls, and unfamiliar markets. Another possibility is to export gold; however, this could only be done by eliminating the gold backing of our currency and raising the price*--which would undercut dollar holders and might actually favor the Soviet Union (a major gold producer). The third and most likely course would be to dispose of foreign investments, as Britain had to do to finance World War II. The U.S. could probably convert its overseas assets into food for several years, if necessary, but at the cost of foreclosing other uses for this capital resource.

The same types of problems would arise, even if none of the stored surplus grain were damaged, if the existing surplus were substantially further reduced preattack by large exports, e.g., under P.L. 840 or by a more "successful" agricultural policy. (The fact that several successive administrations have failed to achieve this objective fully should not obscure the fact that it continues to be explicit national policy.) It is quite conceivable that an aggressive but foresighted Soviet Union, contemplating a policy which might possibly escalate to nuclear war, might start by buying up the U.S. agricultural surplus--at subsidized prices--and converting it to a Soviet stockpile. The potential irony of this situation is too grisly to dwell on.

Without an effective active-passive defense, the number of casualties from a 10,000-MT (fission equivalent) attack might be much larger. In fact, with malevolent targeting and current CD programs, from 50% to 90% of the population might be immediate hostages (depending on details). In the worst case (90%) most of the survivors would be in rural areas; undoubtedly the majority would find a way to live through the first winter, if necessary by slaughtering surviving animals and

*Otherwise, foreign dollar holdings and short-term credit exceed our total gold reserve. To refuse or suspend payment might invite retaliation such as seizure of U.S. property.

preserving the meat by primitive methods, e.g., drying, salting or canning.* The U.S. as an industrial-military power would hardly recover from such a disaster in less than several generations. If 50% of the population survived but most of the urban property (including food) were destroyed, the immediate crisis would be extremely severe. Surviving livestock would then constitute the main food reserve in the CONUS and, without enough stored grain to keep many animals alive over the winter, large numbers would have to be slaughtered and the meat somehow preserved within a few weeks. The organization and execution of this operation would almost certainly be one of the top priority tasks facing a postattack government. Success or failure would make a tremendous difference, for if the meat could not be saved in time (before animals died of disease, exposure or starvation) the only way of feeding the population until the next harvest would be by grain imports (assuming shipping and port facilities were available and other countries had surplus supplies to sell) thereby probably--at the very least--dissipating a substantial fraction of valuable U.S. assets abroad, which would be needed to finance rebuilding.

b. Optimized Radiological and Thermal Attack

Weight: 10,000 MT's (fission equivalent)

Season: Winter or spring

Targets: Mixed counterforce plus counter-environment; same areas as in (a), but croplands are targeted with groundburst weapons; watersheds get a mixture of groundburst and airbursts.

The consequences of the attack would differ from (a) in that standing crops such as winter wheat would not be seriously damaged (except in terms of surface contamination) and stored foodstuffs would remain intact except where the warehouses or silos were located within the blast radii.

A high level of β-radiation on the ground would very likely make farming impossible for at least one growing season. Decay and weathering (which would wash many of the fallout particles into crevices in the soil, where the β-emissions would be substantially shielded) should reduce the initial radiation level by four to five orders of magnitude by the time of the next (e.g. fall) planting.

The loss would be, at most, one season's potential harvest (unless other postattack conditions further delayed the resumption of agriculture). However, an entirely vegetarian diet (lacking even dairy products) may be

*Assuming animals survive about as well as humans. Many animals would be badly scorched and presumably many would receive lethal burns; others would be protected by topographical features, barns, or each other. It must be noted, also, that cattle and sheep would be somewhat insulated against thermal flash by their hairy coats which would singe but, in general, not burn easily.

nutritionally inadequate, especially for a population under considerable stress (not to mention the necessity of working very hard). (See Appendix J.) Moreover, it would be undesirable for humans to consume (directly) grain, fruit or vegetables grown in heavily contaminated soil, due to the hazard from Sr-90. Hence there would be a very strong motivation for heavy dietary reliance as far as possible on meat and (decontaminated) dairy products, even though animal foods are less efficient in terms of Calories per acre. Tables 7-2 through 7-4 indicate some relevant comparisons.

Table 7-2

Quantities of Meat, Poultry, Dairy Products, Grain Products Consumed per Capita by Americans 1959* [4]

	Civilian Consumption lbs. per capita (carcass wt.)	Equivalent Pounds of Feed+
Beef and Veal	81.4	870
Lamb and Mutton	4.8	715
Pork (excluding lard)	67.6	383
Eggs	352 eggs	197
Chicken	28.9	166
Turkey	6.3	33
Total Milk Products	679.0	740
Fish	10.5	
Total		3104

Direct Human Consumption of Various Commodities in lbs. per Capita:

Sugar	96.4	Wheat: as flour	120.0
Peanuts	4.7	as breakfast cereals	2.7
Potatoes	101.0	Rye: as flour	1.2
Sweet Potatoes	7.4	Total Corn Products	28.0
Dry edible Beans	7.7	(Includes corn meal,	
Rice	5.2	syrup, corn starch,	
Oats	3.5	corn sugar, breakfast	
Barley	1.0	cereal, hominy)	
		Total of Above	377

* Figures for 1961 altered somewhat; beef and veal 93.7 lbs., pork 62.2 lbs., eggs 325, etc.

\+ Modification using Table 7-3.

Table 7-3

Feed Equivalence of Animal Products[5]

	Weight of Feed Required for 100-pound Weight Gain
Chickens	302
Hogs	571
Beef Cattle (partly grazed, partly grain fed)	1068
Sheep and Lambs (For each 100 pound live-weight production, 18 pound of wool was produced; grain feeds used only for ewes)	1490
Milk (100 lb.)	109
Eggs (100) (Approx. 11 lb. wt. exc. shells)	56

Table 7-4

Comparison of Various Food*

Food Source	Calorie Production Efficiency Cal/acre / Cal/acre (wheat)	Protein Production Efficiency gms/Cal / gms/Cal (wheat)
Wheat	1	1
Corn	1.75	.87
Potatoes	4	.78
Soybeans	1	3.44
Cabbage	.7	1.9
Milk (cattle fed on Timothy, meadow grass, rye grass, alfalfa and forage)	.85	1.6
Beef (range bred)	(.04) very wide variations	1.6
(pasture and hay)		1.6
Pork (corn fed)	(.25)	(1)
Poultry (corn and soybeans)	(.33)	(4.1)

*Protein production efficiencies are based on median yields and average commercial animals. By raising leaner animals the Calorie production efficiency would drop sharply and the ratio of protein to Calories would consequently rise. Figures simply reflect the protein/fat ratio in meat. Figures for whole milk exclude butterfat beyond "standard." All figures are variable ± 50% at least.

The importance of stored surplus foodstuffs is likely to be two-fold: in addition to providing a margin of safety for short-term human needs, it would facilitate conserving the maximum possible numbers of domestic animals in order to maximize the rate of recovery of normal agriculture and, incidentally, ameliorate the long-term Sr-90 problem. In view of this dual consumption, a potential one-year food supply for the human population might, in fact, last only a few months. To the extent that available supplies fall short of anticipated requirements, the government would be faced with the dilemma of trading short-term disutilities for long-term ones. The better this problem is understood in advance, the better the chance of making the best of a difficult situation if and when the time comes. There is, of course, a third and still more disconcerting possibility: that feeds may be initially diverted to animal consumption (by farmers and stockmen understandably anxious to protect a valuable surviving asset), but supplies prove inadequate or irrelevant to the purpose and animals subsequently die anyway, whether of malnutrition, delayed radiation effects, or epidemic disease.

The importance of this potential dilemma has not yet been generally recognized: the most detailed and authoritative study of postattack agricultural economics[6] assumes that one of the possible "adaptations" to increase postattack food production would be to divert feed grain consumption from livestock to the population. Actually, to the extent that stocks of feed grain held on farms could be used for private purposes by farmers and stockmen and a free market is permitted to operate, and to the extent that the advantage of eating meat to minimize Sr-90 intake became widely known, the likeliest eventuality would be exactly the reverse: cereal grains, including wheat, would be used to feed as many surviving animals as possible. This makes a tremendous difference: if all feed grains were used to feed people, animal Calorie production would decrease by about two-thirds, mostly at the expense of beef, pork and poultry, but over-all Calorie production would almost double. On the other hand, if all cereal grains and root crops currently consumed directly by humans were fed instead to dairy cattle or poultry--the most efficient converters of plant to animal Calories--meat production (excluding milk) would increase by about half, but over-all Calorie production would drop by about a third.*

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*Other things being equal, the most efficient source of animal Calories is milk. Cows grazing on average pasture in the midwest, Gulf or Atlantic states, produce about as many Calories per acre as wheat grown in the drier part of the wheat belt. Dairy cattle consume six times as many Calories as they produce in the form of milk, but part of this inefficiency is compensated by the fact that ruminants (e.g., cattle and sheep) are able to digest cellulose with the help of symbiotic bacteria and therefore can utilize essentially <u>all</u> of the aboveground plant crop, including leaf and stem material, instead of only the seed or fruit. The over-all efficiency for dairy cattle runs around 35-40%, as compared to corn, on land of equivalent basic productivity. Efficiencies of beef cattle are around 20% on the same basis. Poultry do not digest cellulose but, with scientific diet control, broilers can achieve close to 30% efficiency (3 pounds of feed per pound of meat). Hogs and sheep are the least efficient (~ 15%), see Table 7-4.

The total number of Calories available to humans in the second case is one-third the number in the first case, although the amount of meat (not counting dairy products) in the second case is more than twice as great.

It is true, of course, that the strontium-90 hazard is not an immediately lethal one. Adults, for example, may well be able to tolerate relatively heavily contaminated diets (e.g., 15,000 s.u.) for several years without running serious risks. During the first two or three years, while the Calorie shortage is most acute, it might be possible at least to find enough uncontaminated food to provide for the needs of infants, nursing mothers and growing children.

The two large attacks analyzed by S.R.I. provide good illustrations of the potential importance of the dilemma which has been sketched above. (See Table 7-5.) It is noteworthy that in both attacks, regardless of assumed CD programs, agricultural production decreases more than surviving population. The more fallout (and blast) protection the population has, of course, the greater the discrepancy. If the Sr-90 hazard induced a large-scale diversion of cereal, root, and field crops to feed animals--particularly dairy cows and poultry--the surviving percentages for agricultural production would be three times worse as shown by the adjoining figures in parentheses.

Table 7-5

Comparison of Several Cases

Measure Weight:		Counterforce (CF) Attack *	Mixed Counterforce (CF) & Countervalue (CV) *
population survival	no protection	68%	19%
	"available" protection	68%	36%
livestock survival		41%	27%
cropland available		34%	19%
agricultural production**	no protection	25% (~8.3%)	13% (~4.3%)
	"available" protection	35% (~11.7%)	21% (~7%)

*The total number of MT's (19,000 and 23,000) is misleading because these attacks were apparently calculated on the basis of much lower value of $\frac{R/hr \text{ at } 1 \text{ hr}}{KT/mi^2}$ than the "magic number" assumed in Chapter I. The S.R.I. attacks are roughly equivalent to 6-7,000 MT's (fission) in terms of radiological effects.

**Calculated on the basis of the diversion of feed grain to direct human consumption.

A further comparison makes the point still clearer. Preattack population (100%) and preattack agricultural production (100%) could be said to have the ratio unity. The postattack ratios in the four cases, assuming the animal diet, are:

Table 7-6

Summary Comparison

Attack	Calories/cap. (postattack) / Calories/cap. (preattack)
CF - no protection	12.2%
CF - available protection	13.3%
CF + CV - no protection	22.7%
CF + CV - available protection	18.5%

These figures are ominous. Even though the average American consumes around 3500 Calories per day*--whereas 2000 Cal./day might be sufficient for a sedentary person and 3000 Cal./day for an active one--the gap evidently cannot be closed by belt-tightening or any combination of simple efficiencies.

It is difficult to avoid the conclusion that in the first few years after a large attack it will not be possible to feed the entire population on a diet relatively free of Sr-90 (i.e., a meat-milk diet), at least without undertaking heroic, uncertain and very expensive countermeasures. On the other hand, with proper organization, the more restricted needs of the most vulnerable segment of the population (infants and children) can very likely be met.

3. Overview

The arguments presented in this chapter tend to support the conclusion that the crux of the environmental recovery problem is to feed the surviving population in the short run while preserving as large a number of domestic animals as possible, as a "mobilization base" for subsequent agricultural recovery. Among the reasons for stressing this are (1) the fact that a vegetarian diet is likely to be nutritionally substandard** and (2) the fact that such a diet would compromise the possibilities of minimizing the Sr-90 hazard over the longer term. For larger attacks involving substantial amounts of fallout over farmlands, the two objectives are to some extent incompatible and postattack agricultural policies may require very hard decisions. Moreover, the consequences of indecision or a wrong decision could be to waste feed grains on animals which will later die anyway.

*Not counting exports amounting to about 500 Cal./day/person.

**Unless extensive vitamin and mineral supplements are added.

As we have suggested in Chapter V, one's notions about the social disutility of an attack are most nearly satisfied by a non-linear function of fractional damage and a roughly linear function of recovery time. The least unsatisfactory of the several simplistic recovery models which were analyzed involved considering the recovery process in terms of a set of discrete tasks, rank-ordered according to relative priorities. Since the setting of priorities requires balancing a variety of disjoint interests, ranging from military to social to aesthetic, the question of criteria is non-trivial (Chapter V). Without a well-defined set of criteria, however, one cannot, even in principle, discuss recovery (or disutility) in quantitative terms. However, for large attacks employing groundburst weapons (barring overwhelming postattack military commitments, e.g., to defense of Europe or the CONUS from invasion), it is not unreasonable to suggest that steps to ameliorate the short vs. long-term dilemma would generally be rated toward the top of the list.* The cost and potential effectiveness of various types of countermeasures is clearly an issue of the first importance. In the following chapter we will examine some of the possible ways of ameliorating the situation, both preattack and postattack.

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6. K. Moll, op. cit.

7. U.S.D.A., op. cit.

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*It is worth recalling that infants, whose bodies are building new bone, are most vulnerable to the Sr-90 hazard.

CHAPTER VIII

COUNTERMEASURES

In this chapter we shall list and discuss a number of measures which might be taken either before or after an attack, primarily to ameliorate the short- vs. long-term "squeeze" outlined previously, and secondarily to minimize some of the other potential postattack environmental problems which have been alluded to. The various approaches would probably be undertaken in combination, so that they should not be thought of as mutually exclusive alternatives. However, for what it is worth, they are listed roughly according to ou stimate of the cost-effectiveness, i.e., the cheapest, most effective measures first.

1. Land Classification

Land might be graded according to level of contamination. The most contaminated land (e.g. above .1 KT/mi^2) could be temporarily retired--i.e. placed in a "soil bank"--and the owners or occupiers encouraged to relocate elsewhere, perhaps at government expense. To the extent that industrial markets exist, contaminated land may be used to grow non-edible crops such as fiber, oil, or timber.

An alternative, which would probably be preferred (indeed necessary) in the case of large attacks, would be to designate all heavily contaminated land as exclusively for the production of animal feeds, assuming enough livestock had survived the attack or could be imported from other parts of the world to utilize the resulting production.

If the attack were not a massive one it is quite conceivable that by judicious re-allocation on the above basis total agricultural production could be maintained at a level not far below the current one. On the other hand if the attack is so large, or so deliberately aimed at agricultural productivity, that little or no land remains free of contamination, the consequences could be a severe food shortage. Stockpiles and imports would be of critical importance in such a case. See Sections 5 and 6.

The efficiency of a classification system would depend to some extent on the smallest discrete land unit which can be effectively handled by the damage assessment system. Thus, if testing and enforcement facilities are scarce it may initially be necessary to deal uniformly with whole counties or groups of counties. This would result in over-all inefficiencies, as well as individual hardships, since an entire county might have to be treated as would befit the most heavily contaminated fields within it. (This suggests that a capability for extensive and rapid postattack radioactive monitoring of rural areas may be an effective countermeasure.)

2. Food Classification

It might be possible to cause foods to be labeled by the processor or distributor under government supervision according to level of Sr-90 contamination. Two basic options would be open: (1) if the problem were not too severe, the free market might be allowed to determine the prices of the foods in the various categories, resulting in a higher retail price for the less contaminated foods. This would encourage farmers and food processors to actively seek methods of decontaminating foods, and to fully exploit the least contaminated sources. (2) If the general level of contamination were higher, a rationing system might be desirable. Such a system might restrict the least contaminated foods for consumption by pregnant or nursing mothers, infants and young children.

The first option might be relatively inexpensive in terms of direct government expenditures, but higher costs would be likely for consumers of relatively uncontaminated food. The second option would involve the considerable administrative expense of a rationing system with suitable provision for enforcement, and of course the likelihood of some "black marketing" with its associated social costs in terms of demoralization and corruption. On the other hand, where enforcement is successful, the overall impact on the economy may be somewhat stultifying.

A third option which would probably be combined with either (1) or (2) is to simply restrict the uses of certain foods to animal consumption or industrial use. If the supply of relatively safe foods is sufficient, this technique if used alone would have the social advantage of not discriminating on the basis of ability to pay, and not requiring cumbersome rationing machinery. However, the penalty would be that infants and children would suffer the worst effects, i.e., the young would be discriminated against.

3. Food Decontamination

An ion-exchange process for removing Sr-90, Sr-85, I-131, and other isotopes from liquid milk has been developed by several research organizations, notably Ionics Corporation (Cambridge, Mass.), the Dairy Products Division of USDA (Beltsville, Md.), and R.A. Taft Engineering Center of the U.S. Public Health Service. The process may achieve 90-95% efficiency or better on a large-scale basis, at a direct (preattack) cost estimated to be one cent per quart or less.[1]

Certain other foods, such as fruit or vegetable juices and purées, may possibly be decontaminated by similar techniques although existing technology is inadequate. Citrus and other tree fruit juices, tomato juice, grape juice or wine, and beer would be especially appropriate for such treatment, especially since leafy vegetables (principal sources of vitamins A and C) may be hard to decontaminate and therefore undesirable. It is not clear that ion-exchange processes will necessarily work efficiently in these cases, however.

The potential importance of decontaminated milk (if dairy herds survive) and juiced fruits or vegetables in the postattack world is suggested by the fact that leafy vegetables and fruits currently supply about 73% of dietary ascorbic acid (vitamin C) and milk products supply about 7%. The same groups supply 48% of dietary vitamin A, while milk products (excluding butter) supply a further 14%. In contrast, grain products--our principal stored food surplus--provide essentially no vitamin C and less than 1% of dietary vitamin A.[2]

Costs can only be based on the current estimates for milk alone. A plant costing $1 million would supply 500,000 people at the rate of 100 quarts per year per person. The needs of the whole population could be accommodated for an outlay of roughly $.5 billion. To handle fruits and vegetables as well might double this figure. Spread over five years or so, the indicated outlays would seem to be roughly in line with the level of expenditures currently being contemplated in connection with "extensive" CD programs ($15 billion/year) or conceivably with "moderate" programs ($5 billion/year).[3]

If the food decontamination program were to be put into effect in the postattack world on a "crash" basis, the costs might be much higher to the extent that there were competing high priority requirements for the same resources and skills, and because of the inevitable inefficiencies engendered by haste. At best, several years would probably elapse before all milksheds could be covered; on the other hand, the most contaminated areas could receive attention first. A series of prototype plants and possibly a postattack "mobilization base" would be cheaper and reduce time delay later.

4. Land Decontamination or Protection

If farm lands were heavily contaminated with Sr-90, classification and food decontamination might not in themselves be sufficient. On the other hand, land decontamination would certainly be very expensive. The simplest procedure--where appropriate--is the addition of lime to acid soils. This may reduce Sr-90 uptake by factors of 3-4 in exceptional cases, but more typically by a few per cent. It is not applicable everywhere.

A second technique is to plant deep-rooted crops such as alfalfa, since the Sr-90 is usually confined near the surface. Alternatively, it is sometimes feasible to "deep plow" and disperse the Sr-90 through a greater depth of soil, and then plant shallow-rooted crops. Again, 25%-50% reduction is about as much as can reasonably be expected by this means.

These techniques are only useful, in any case, to the extent that crop distribution patterns may be conveniently rearranged for the purpose. A more drastic method is to strip off a layer of topsoil (or a disposable "cover crop" such as sod) and carry it away. A reduction factor of about 10

is attainable if the stripping is done promptly before plowing and planting. The technique is also obviously expensive and wasteful of valuable topsoil. Only in areas where the soil is relatively deep and fertile (e.g., Iowa and Illinois) would the technique seem to be economic.

An interesting possibility has emerged as a result of recent experiments with Sr-85 in Denmark.[4] The basic method is to mix certain inorganic fertilizers (such as calcium dihydrogen phosphate, potassium dihydrogen phosphate or "super phosphate") into the soil and apply a heat treatment. Extractability of strontium ions decreases sharply to as little as 1% of the original value as a function of the temperature (up to 1000° C.) and the length of time of the treatment (up to 24 hours). Even with no chemical additives and only half-hour heating, at 800° C. the solubility was reduced to 3% as compared to 93% initially. However, humus and organic matter in the heated layer would be destroyed. The mineral residue would have to be mixed with the deeper layers of soil to prevent it from blowing away with the first wind after the heat treatment.

It is just barely conceivable that such a process could be developed to the point where contaminated topsoil could be continuously stripped, treated and returned to productivity with the radiostrontium in insoluble form. The primary advantage of heat treating soil on the spot and immediately returning it would be a modest saving in the cost of transportation to and from the disposal sites which would otherwise be needed, plus the cost of land for the sites themselves, which could easily amount to 10-20% of total farm area. In addition, the returned inorganic mineral soil would have some (slight) fertilizing value. To clear topsoil to a depth of 2 inches from a single 160 acre farm (1/4 mi^2) means transporting 42,000 cubic yards of material at a presumed cost close to \$.15 per cubic yard (even if the distance moved is relatively short--say to the edge of the field). A bulldozer or scraper and a tractor-towed mobile heat treatment plant might handle the job. Extensive land decontamination seems likely to be quite expensive. On the basis of current estimates such as are given above, costs of \$40-\$45 per acre seem indicated. This is comparable with the basic price of land in some of the less fertile or drier regions and would certainly add significantly to over-all land costs. It would mean an outlay of the order of ~ \$4 billion if 100,000,000 acres were involved (15-20% of the arable land in the U.S.). This expenditure is about 10% of the agriculture sector of the GNP in recent years. Roughly \$100,000 worth of equipment (scrapers, tractors and tires) would be "used up," or totally depreciated, in scraping 6400 acres or 10 mi^2 to a depth of 2 inches. The basic equipment cost alone would be \$15-\$16 per acre, or roughly \$1.5 billion at preattack prices. In a postattack economy such equipment would be needed for numerous other urgent tasks, such as rubble clearing, and would therefore be proportionately more valuable than preattack. Unless the government subsidized all decontamination, the cost of food production (including amortization and capital costs) would certainly rise and many farmers would find themselves in a credit squeeze. Worse, the cost of decontamination, at so much per acre, regardless of productivity would mean that low-yield lands might become uneconomic to farm at all while more productive regions would not, resulting in a severe dislocation of the rural economy. In this case, less productive acres might go out of production, leading to further indirect food price increases because of shrinking supply.

An attractive possible supplement, or even alternative to the above would be to protect the soil before the attack (during a period of intense crisis) by covering it with a very thin polyethylene film which could subsequently be rolled up and disposed of. Since the film is sufficiently porous to transmit water vapor, it is possible for seeds to germinate and grow under it, much as in a hothouse. Such films are commonly sold and used for mulching purposes today* at prices equivalent to roughly $100/acre for .0015" film. It is possible that further developments in the technology, larger scale purchasing and production, and/or the use of thinner films might cut the price to a level competitive with scraping and removal of soil. Since no topsoil would be lost, and the decontamination would be nearly 100% efficient (rather than 90%, which is about tops for a mechanical process), the use of protective films has much to recommend it even at the higher price, especially for highly productive "premium" land such as the irrigated fields in Arizona and California.

5. Stockpiles

Several sorts of stockpiles should be considered: their relative utility depends somewhat on the specific threat. The existing store of surplus foodstuffs owned or held as security for crop loans by the Commodity Credit Corporation as shown in Table 8-1 would be roughly sufficient to feed the entire population of the U.S. on a 3,000 Cal./day diet for about one year.

Table 8-1

Commodity Credit Corp. Stocks[5]

	CCC owned bushels (Thousands) As of March 31	Total Potential As of July 1	Pounds (millions) As of March 31	Calories** (billions) As of March 31
Wheat (10% bran)	640,809	829,277	38,400	57,600
Corn	693,495	1,327,061	37,400	59,800
Sorghum (6% bran)	551,373	660,564	30,900	46,400
Oats (20% bran)	30,934	98,224	980	1,470
Barley (20% bran)	20,889	43,450	1,050	1,570
Dry Skim Milk			209.9	345

The above figures reflect a substantial (~ 50%) decrease since the peak (roughly 1961), as indicated by the following figures for CCC owned stocks:

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*By Du Pont Co., Gering Plastics Co. (Div. of Monsanto Chemical Co.) and by Visqueen Div. of Ethyl Corp.

**Assuming 1600 Cal./lb. for corn and an average of 1500 Cal./lb. (allowing for some indigestible bran) in the rougher whole grains. Dry skim milk contains 1643 Cal./lb.

	Corn (as of Jan. 1) thousands of bu.	Wheat (as of July 1) thousands of bu.
1961	1,448,000	1,205,000
1962	1,216,000	1,093,000
1963	958,000	1,115,000
1964	794,000	n.a.
1965	693,000 (March 1)	830,000 (est.)

There are other substantial food stocks not included in the above table, including livestock, inventories of processed food and inventories of unprocessed food held by food processors and others. The USDA has estimated that there were about 15.5 days' food per person in retail (1962 est.) and 16 days' in wholesale* (1963 est.) inventories, plus 7 days' in homes. There were also about 45 days' supply in manufacturers' stocks as of 1958.** These figures are not likely to have changed much.[6]

The diet which the existing food stockpiles would make possible is analyzed in Table 8-2. As the table shows clearly, such a diet probably would be inadequate unless it would be supplemented by the addition of certain elements, notably vitamins A, B_2 (riboflavin), B_{12} and C, plus calcium--which are extremely scarce or absent in grain.

To obtain maximum benefit from the U.S. "Calorie Stockpile," therefore, it would probably be worthwhile to purchase and warehouse the necessary quantities of supplemental synthetic vitamins and calcium to make possible a reasonably balanced diet for the survivors. Otherwise resistance to infection and capacity to work would be drastically decreased, diseases of malnutrition such as scurvy might be widespread, and actual starvation might occur in some cases.

In 1963 U.S. production of synthetic ascorbic acid (vitamin C) was 7,851,000 pounds at a unit value of about $2.09 per pound.[7] Assuming a minimum daily requirement of 50 milligrams, one year's production would suffice to provide a one-year resource supply for the entire population. Assuming the industry is operating at 80% of capacity, such a stockpile could be built up over a five-year period for about $16 million dollars. The amount needed might actually be somewhat less, assuming current inventories would be available at the time of the attack.

Vitamin A production in 1963 was 498,908 billion USP units worth $50 per billion units.[8] Daily requirements are 5000 units of which a dietary deficit of 3500 must be made up; hence a full year's reserve supply for the whole population is equivalent to about 6 months' production. Again assuming 20% excess productive capability, a stockpile would take 2-1/2 years to accumulate and would cost about $18 million.

*80% of which are in cities.

**69% of which are in standard metropolitan areas with more than 40,000 manufacturing employees.

Table 8-2

3,000 Cal./Person/Day Diet Based on Existing Stockpiled Grains

35% Wheat Grain
37% Corn Meal
28% Sorghum Grain

	Wheat	Corn	Sorghum	Total	Min. Daily Requirements* Men	Women	Infants	Ratios Total Diet / MDR
Food Energy (Cals.)	1056	1078	830	2964	3000	2200	lb x 54.5	1
Calcium (g)	.131	.068	.07	.269	.8	.8	.600	0.33
Phosphorus (g)	1.177	.830	.718	2.725	.3	.3		9.0
Iron (mg)	10.4	6.5	11	27.9	10	12	5	2.9
Potassium (g)	1.184	.880	.875	2.939	1.5	1.5		2.0
Vitamin A (I.U.)	0	1519	0	1519	5000	5000	1500	0.3
Thiamine (mg)	1.75	1.15	.95	3.85	1.5	1.1	.4	2.5
Riboflavin (mg)	.384	.372	.375	1.13	1.8	1.5	.5	0.6
Niacin (mg)	13.7	6.8	9.75	30.25	20	17	6	1.5
Ascorbic Acid (mg)	0	0	0	0	75	70	30	0
Protein (g)	41.9	27.6	27.5	97	70	58	lb x 1.5	1.4
Lysine (g)	1.2	.89	.72	2.81	.8	.8	ratio of lysine / tryptophan = 2.81 (ideal: 3)	
Methionine** (g)	.64	.57	.45	1.66	1.1	1.1		
Cystine (g)	.92	.40	.45	1.77			ratio of cystine & methionine / tryptophan = 3.43 (ideal: 3)	
Tryptophan (g)	.54	.18	.27	.99	.25	.25		

3,000 Cal. Diet Contains:
1050 Cal. Wheat = .7 lb = 11.2 oz = 320 gm
1110 Cal. Corn = .69 lb = 11.04 oz = 310 gm
840 Cal. Sorghum = .56 lb = 8.96 oz = 250 gm

*MDR's for men age 45, women age 45 and infants 2-6 mos.

**In a diet containing no cystine; cystine is convertible to methionine but is not considered essential *per se*.

Synthetic vitamin B_2 (riboflavin) production in 1963 was 577,000 lbs., worth $10.70 per pound. Minimum daily requirements are about 1.8 mg., of which about 1.1 are provided by the mixed grain diet and the remainder must be supplied separately. For the whole population, this deficit amounts to about 10^5 lb. per year, which is equivalent to about 1-month's normal production. Based on 1963 prices, the cost of such a stockpile would be about $1 million. The cost of a B_{12} stockpile is hard to estimate because minimum daily requirements are unknown. If we assume ~ 2 micrograms/capita/day, a 1-year stockpile could be obtained for about $3 million (2-months' normal production).

Calcium gluconate production in 1963 was 608,000 lbs., worth $.60 per lb. Minimum daily requirements of calcium are about 0.8 grams of which only one-third is supplied by the mixed grain diet. A supplement of about 0.5 gm. (calcium) or 5.5 gm. of calcium gluconate per capita per day must be provided. A reserve supply of calcium gluconate for a full year would be expensive and bulky: approximately 10^9 lb. (more than 1000 years' normal production), worth $600,000,000 at current prices. However the compound is intrinsically cheap and easy to produce, and given such a requirement, it could certainly be manufactured relatively quickly and much more cheaply.* Inorganic calcium compounds such as calcium phosphate or calcium carbonate (lime) may also be utilized in an emergency, so that the mineral can probably be supplied in some form--if not the most palatable--even if no preattack preparations are undertaken. However there would seem to be sound arguments for stockpiling enough calcium gluconate, or its equivalent, for a month or so. An alternative worth considering, perhaps in a period of intense crisis, would be to divert some current dairy production to building up a supply of dry skim milk--useful not only as a source of calcium but for protein also.

Another category of stockpile items worth considering might be agricultural inputs. In the case of perhaps greatest concern, a massive attack involving a large number of groundburst weapons and correspondingly heavy fallout, a very large number of farm animals might be radiation casualties. Others might have to be slaughtered because of shortages of feed. To minimize the postattack Sr-90 hazard it would be imperative to rebuild dairy herds, in particular, as quickly as possible. Ideally one would wish to concentrate on the best purebred strains of livestock, for the simple reason that a champion milk cow can produce more than six times as much milk in a season as the U.S. average.** If current supplies are inadequate it would require considerable sacrifice to divert the best cows from milk production for purposes of calving. The utility of the sacrifice would be maximized, however, if each such cow could be bred with a blue ribbon bull. Hence a stockpile of (frozen) sperm from champion bulls suitable for artificial insemination could be an extraordinarily valuable high-leverage asset in the postattack world. A supply of sperm costing a few million dollars at prewar market prices, suitably subdivided into optimum "doses" might

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*Although the federal government might have to build the plant.

**The single season record for one cow in the U.S. is more than 42,000 lbs. of milk, whereas the average is around 7000 lbs. per animal, and the average for registered (purebred) herds is about 12,000 lbs. per animal.

conceivably make a difference of 50% or more (depending on the status of surviving breeding stock) in the speed of recovery of dairy production, although this is a difficult conjecture to substantiate without considerable study. Such a supply might be accumulated relatively quickly, e.g., in a severe crisis.

Other agricultural inputs would be much more expensive to stockpile, but the numbers are of interest:

Table 8-3

Input	Cost of 1 year Stockpile (1962)[9]	Utility
Pesticides	~$ 500 million	+ 20%
Seed	539 million	+ 17%
Fertilizer & Lime	1,542 million	+ 25%
Vehicle operation, inc. fuel	<3,241 million	<+1[illegible]%-exact fig. n.a.
Feed	5,470 million	+ 50% (animal production only)

The potential utility, in terms of improved agricultural performance (beyond what would be expected otherwise) is given as a percentage in the last column,* which is based on the results of the SRI study of postattack farm problems,[10] assuming for purposes of argument that none of these inputs would otherwise survive. The above costs are probably somewhat exaggerated for two reasons: some supplies of all of these inputs would certainly be available even in the first year; moreover, probably three-quarters of the benefit could be had for half the cost by careful allocation. Nevertheless, even without animal feed, the expenditure involved would be rather impressive-- several billion dollars.

An interesting measure of comparative cost-effectiveness is the dollar cost for each 1 per cent of postattack agricultural improvement.

Pesticides	~ $25 million	
Fuel	~<$30 "	(exact figures unavailable)
Seed	~ $30 "	
Fertilizer and Lime	~ $61 "	

On the basis of this list the best candidates for stockpiling would be fuel or pesticides, although the differences are not particularly dramatic.

Another sort of "stockpile" worth discussing would be a subsidized fishing industry capable of supplying a really substantial proportion of

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*If the loss would be -33%, compared to preattack, the postattack utility of a 1-year stockpile would be +50%.

the diet. Since the average person in the U.S. consumes only 10 5 pounds of fish per year--much of it imported from abroad or from Alaska--compared to about 90 pounds of red meat, 352 eggs and 679 pounds of dairy products (see Chapter VII, Table 7-2), it is clear that the magnitude of the investment required to make a substantial difference in the role of fish would be enormous. In addition, the major commercial fishing grounds, such as the Grand Banks off Newfoundland, and the waters of the Humboldt current in the Pacific, are extremely well-fished already.* Nevertheless, as the major naval power in the world, the U.S. might conceivably find multiple uses for such a fishing fleet (as the Russians obviously do) which would help justify the considerable cost. It is very difficult to be quantitative about the cost of the program for several reasons, but--apart from capital outlays--one rather suspects it would be at least comparable to the wheat support program in magnitude, i.e., in the billions of dollars per year.

6. Imports

Essential agricultural commodities which have not been stockpiled and cannot be produced domestically in sufficient quantity would have to be imported, assuming, of course, that shipping and port facilities are available. It is relevant to consider the likely foreign sources of such imports.

There are only a few countries in the world with exportable surplus agricultural production. The European countries (e.g. France, Denmark) are excluded from the following on the grounds that their trade is essentially entirely within Europe which, altogether, is a net importer of food.

The most portable (quantity) foodstuffs are grain and dry skim milk. The following table shows the annual production in the six major "surplus" countries, together with the comparison with current U.S. production:

Table 8-4

1962 Production in Thousands of Metric Tons[11]

	Australia	Argentina	Brazil	Canada	N.Zealand	Uruguay	Total Compared to U.S.
Wheat	8,353	5,020	-	15,392	251	452	1.0
Corn	178	4,360	-	813	-	206	.06
Oats	1,067	487	-	7,612	27	-	.62
Rice	135	178	5,650	-	-	77	2.06
Rye	-	163	-	306	-	-	.45
Barley	890	345	-	3,612	92	35	.52
Soybeans	-	-	350	180	-	-	.03
Milk	6,768	4,483	5,464	8,764	5,413	751	.55

The significant column is the last one. It shows that total production of wheat in the six countries together is about equal to U.S. production. If U.S. wheat, about half of which is exported, were removed from the world

*The Russian, Norwegian, Icelandic, Japanese, British and Peruvian fleets are particularly active. The bitterness of some recent quarrels over offshore limits (Peru vs. U.S., Britain vs. Iceland, etc.) testifies to the intensity of competition.

market, it is safe to say that outside production could scarcely meet the demand from other countries, e.g. Europe and the Communist Bloc, without providing for shipments to the U.S. Prices would certainly rise drastically, quite possibly by a factor of five or ten (or 100), as a world glut was instantaneously converted into a world shortage. The possibility of importing substantial quantities of other grains, e.g., for animal feeds, can be virtually dismissed completely. Total corn production in the six countries all together amounts to only about 6% of U.S. The situation with soybeans is even worse. In the case of oats, barley and rye the disparity is not so extreme, but obviously there is no hope of replacing any worthwhile fraction of lost U.S. production from foreign sources. Similarly there is essentially no possibility of importing dairy products, in any form, in amounts sufficient to be meaningful: the six countries in toto account for only 55% of the U.S. production. Exportable surpluses are clearly much smaller.

As regards possibilities of importing livestock to provide a meat diet and rebuild depleted herds or flocks, the situation is slightly but not notably better:

Table 8-5

1962 Livestock Numbers in Thousands of Head[12]

	Australia	Argentina	Brazil	Canada	N. Zealand	Uruguay	Total Compared to U.S.
Cattle	18,033	43,300	76,176	10,940	6,598	8,835	1.64
Swine	1,653	3,075	50,051	5,138	686	-	1.05
Sheep	157,712	47,300	19,168	984	48,981	22,300	9.5

To replace only half of the 100,000,000 cattle in the U.S. would require about one third of the herds in the six meat exporting nations (mostly from Argentina and Brazil, where diseases such as bovine TB and hoof-and-mouth are still a serious problem). If the purchases were spread over several years--probably necessary in any case because of lack of shipping--the impact would be somewhat less acute, but prices would nevertheless certainly react sharply upward, possibly doubling or more.

For various reasons, including intrinsic inefficiencies in converting plant to animal Calories (e.g. as compared to poultry), and domestic shortages of feed grain, large-scale importing of live pigs seems unlikely. However, since pigs produce large litters, numbers can be built up comparatively quickly if and when feed becomes plentiful.

There is a possibility of replacing cattle to some slight extent by sheep. They require no special feeding, and can forage successfully on less productive pastures than cattle. Other countries, particularly Australia, New Zealand and Argentina, have much larger standing populations than the U.S. On the other hand it must be remembered that it takes

something like 11 sheep to equal one steer in terms of meat--whence 100,000,000 beef cattle are equivalent to the order of one billion sheep. There is no standing population anywhere in the world with numbers of this magnitude, even if the animals could be shipped.

The major open question is to what extent, or at what price level, world production (outside the U.S.) could expand to meet higher demands. If one estimates simply on the basis that U.S. Calorie production is about 10% of the world's total, it is not implausible at first sight that production elsewhere could easily expand (or consumption shrink) to take up the slack. For various reasons this seems too simplistic and too optimistic a viewpoin Major food producers (on an absolute basis) like China and India would literally have to starve their own people to sell any substantial amount of food to the U.S. Some governments might conceivably be willing to do this, up to a point, if the price were high enough, but this seems a thin source of support, at best. Britain, Germany, Japan and other highly industrialized European countries are not self-supporting in food production (despite a strong political motivation to achieve self-sufficiency) even though some of them artificially support prices above the world level. In most non-European countries, other than the six named, production is mainly organized on a traditional tribal or semi-feudal basis which would be extremely difficult to alter quickly without forcibly dispossessing the resident farmers.* Under present conditions it is not clear that food production in these areas is particularly sensitive to price levels; farmers using primitive or traditional methods would, in general, be unable to plant more acreage or otherwise increase output markedly without employing modern technology or having it somehow imposed on them from witnout. Their reluctance to embrace new techniques is probably to a large extent independent of cash income. In any case the methods used in American agriculture require substantial working capital and a well-developed local infra-structure including transportation, fuel, electric power, specialized skill, storage and processing facilities, credit, a commodity exchange, a distribution system, a stable currency, an enlightened tax system, a reasonably literate and mobile labor force, weather forecasting, disaster insurance, and so forth. These things can only be exported gradually (and painfully) if at all. Even if the skilled people (e.g., U.S. expatriates) were available and the political environment were favorable, the other essential components would take many years and enormous effort to build up.

The conclusion of this discussion seems inevitable: it is almost inconceivable that major U.S. deficits (~ 50%) either of grain or livestock could be made up quickly or easily by means of imports. World surplus production outside the U.S. is simply too small to take up the slack. The inevitable consequence (barring massive government intervention) of the U.S. entering the world market as a big buyer, rather than as the biggest seller, would be a spectacular, if possibly temporary (a few years), rise in prices which would be passed along the line to domestic as well as foreign consumers. That this would severely reduce the U.S. postattack SGNP is heuristically clear, although quantitative estimates of the interaction would require a rather deep economic analysis which cannot be undertaken here.

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*Excluding the output of plantations run by Europeans which are, however, largely devoted to such commodities as tea, coffee, rubber, bananas, copra, cocoa, sugar cane, etc.--each of which represents a long-term investment.

7. Protection for Animals

In view of the potential importance of animals in postattack agriculture, especially if many weapons have been groundburst, it is worth considering whether there are any plausible means of providing some artificial protection against fallout. Apart from extensive and inordinately expensive shelter construction programs, the possibilities appear to be limited to:

a) making optimum use of such shelters as already exist (e.g. barns),
b) protecting these structures as far as possible against fires or other threats,
c) enhancing their PF's by available expedients such as sand-bagging and covering windows,
d) stocking them with food and water.

Although these measures are not very sophisticated, it is clear that they may make a great deal of difference in some circumstances. The basic principles of radiation exposure control for animals are not unlike those which would be applicable to shelters for humans, and costs and logistics can be analyzed in fairly similar terms.[13] The subject could be discussed at very great length, but the most important point can probably be made without going into such detail: if the general level of fallout is such that an unprotected animal would receive a dose of less than, say, 1500 R then improvement factors of 3 or 5 could be crucial. If the general level is higher, on the other hand, it is probably not worthwhile taking serious risks. It would be extremely important to know, in time, which situation prevailed. In the first case, a farmer would have to estimate, as best he could, the trade-offs between increasing his own cumulative dose by emerging from shelter to care for the livestock in his barns, and the more immediate economic costs of losing animals which might otherwise survive through exposure, thirst or starvation. In the second case, a farmer would be better advised to write off his livestock as probable losses, and concentrate on protecting himself and his family as well as possible. The more accurate the information available, the less chance there would be of incurring unnecessary human or animal casualties. Hence it is very possible that the cheapest, highest "leverage," countermeasure would be simply the provision of adequate information.[14]

Beforehand, e.g., during a preattack period of tension, this would probably amount to an intensive educational drive to increase general understanding of the nature of fallout and ways of increasing existing PF's both for the farmer and his family and for his livestock. Subsequently, it would be important to provide supplemental data perhaps by radio, on the extent of the local radiation hazards. A simple direct-reading portable instrument which would record the cumulative dose for each individual moving about, and for several fixed locations (e.g. in the barns) would be still more valuable in enabling people to judge the extent to which it is safe to carry out normal functions.

Apart from the somewhat banal remark that information is intrinsically fairly cheap, it seems inappropriate to comment further here on the question of costs.

8. Synthetic or Quasi-Synthetic Diets

The ultimate in decontamination procedures would be to produce all the essential nutrients for human life by industrial chemical methods which would permit absolute elimination of unwanted elements such as radio-strontium and radio-cesium. Synthetic diets, in experimental quantities, cost around $12 per person per day.* Production in quantities large enough to feed the entire U.S. population (or even a sizable fraction thereof) at prices which most people can afford to pay would require many years or even decades of intensive development.

A possible compromise would be to cultivate single-celled micro-organisms in controlled environments. One possibility which has received a considerable amount of attention in connection with the space program is the photosynthetic green alga *Chlorella pyrenoidosa*, which can be grown in a medium containing only inorganic salts.[15] Algae can in principle be used directly as human or animal food, although the protein is not easily digestible and is deficient in the sulfur-containing amino acids, methionine and cystine.

Brewers' yeast is another possible quasi-synthetic food. It can be grown in an aqueous medium containing carbohydrates or sugars such as glucose or sucrose with the addition of small amounts of phosphoric acid and ammonia. The required sugars can be obtained from black-strap molasses, or produced on a large scale from starch or raw cellulose by simple chemical means, e.g., boiling in dilute acid. The fermentation technology is further advanced than alga-culture and, of course, brewers' yeast is used in the making of beer as well as in special dietary foods such as Metrecal. Beer tanks can be converted into yeast propagation tanks by the relatively simple installation of perforated aeration tubes in the bottom, and provision of ducts to remove the air from the top of the vessel.[16] It is quite possible that surviving breweries could be put to work after an attack producing high protein yeast as a food supplement rather than beverages. The attractive feature of the scheme is that assorted "green stuff," too contaminated by various radio-nuclides for humans to consume directly, could be converted to soluble carbohydrates and sugars, decontaminated by means of cheap ion-exchange processes, and then used as a basis for re-creating the protein which is essential to life. Brewers' yeast is fairly easy to digest (after an initial adjustment period) although relatively unpalatable.

Recent research suggests the possibility of a different fermentation approach, namely to cultivate micro-organisms in heavy petroleum fractions. Assuming the necessary trace elements are supplied, petroleum hydrocarbons can be reconverted into edible protein concentrates with an efficiency of close to 50%. The process has been under development since 1957 in France and elsewhere. It has not yet reached the commercial stage, but is considered so promising that large investments are currently being made in expanding the research effort. Protein produced by fermenting petroleum is a potentially valuable complement to the vegetable-proteins discussed above, i.e., they are rich in sulfur-containing amino acids but poor sources of others which are plentiful in grains or yeasts.[17]

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*Based on reports in the press.

It is difficult to make cost estimates for programs involving large-scale chemical synthesis, alga-culture or fermentation technology, since these are all still comparatively undeveloped. They should nevertheless be considered as possible countermeasures, insofar as technology may change prior to a hypothetical nuclear attack.

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APPENDIX G

MATHEMATICAL MODELS FOR DISUTILITY

The disutility calculation specified by the tentative definition in Chapter V evidently depends on the choice of recovery model. For example, in case (i) the indicated integration gives

$$\bar{U}_{(i)} = \int_0^T \left[1-(1-D)e^{t/\tau}\right] dt = T-(1-D)\left[e^{T/\tau}-1\right]\tau$$

$$= -\tau\,[D+\ln(1-D)] \qquad (1)$$

where $T = -\tau \ln(1-D)$ as noted earlier.* It is interesting to compare (1) with the _ad hoc_ derivation in the footnote of page G-3. The major difference is seen at small values of D, where one can use the power series

$$\ln(1-D) \cong -D - 1/2D^2 - 1/3D^3 \ldots\ldots\ldots$$

whence

$$\bar{U}_{(i)} \cong \tau\left[1/2D^2 + 1/3D^3 + \ldots\ldots\right] \qquad (2)$$

The _ad hoc_ model starts with a linear relationship (for small D), whereas (2) starts with a quadratic one.

In case (ii) the integration gives

$$\bar{U}_{(ii)} = \int_0^\infty \left[1-1 + De^{-t/\tau}\right] dt = D\tau. \qquad (3)$$

We now observe that (1,2), based on the compound interest model (i), are indeed non-linear as regards the relation between disutility $\bar{U}$ and damage D, which is consistent with our intuitive understanding of the non-linear relationship between disutility and damage (see Figure G.1). On the other hand, the relationship (3) derived from the equilibrium growth case (ii), is linear in D, contrary to the requirement just mentioned. In both cases, however, the expected linear relationship between $\bar{U}$ and a time constant τ is maintained.

In effect we must reject (ii) because of the inappropriate linearity just noted (apart from other objections) while the previously stated arguments against (i) are still unanswered. In effect, one is forced to conclude that the proposed analogy between recovery and growth is unacceptable. A third model is needed which contains some qualitative features of (ii) but also explicitly takes account of the compartmentalization and internal structure of the economy and the fundamental differences between repair and growth.

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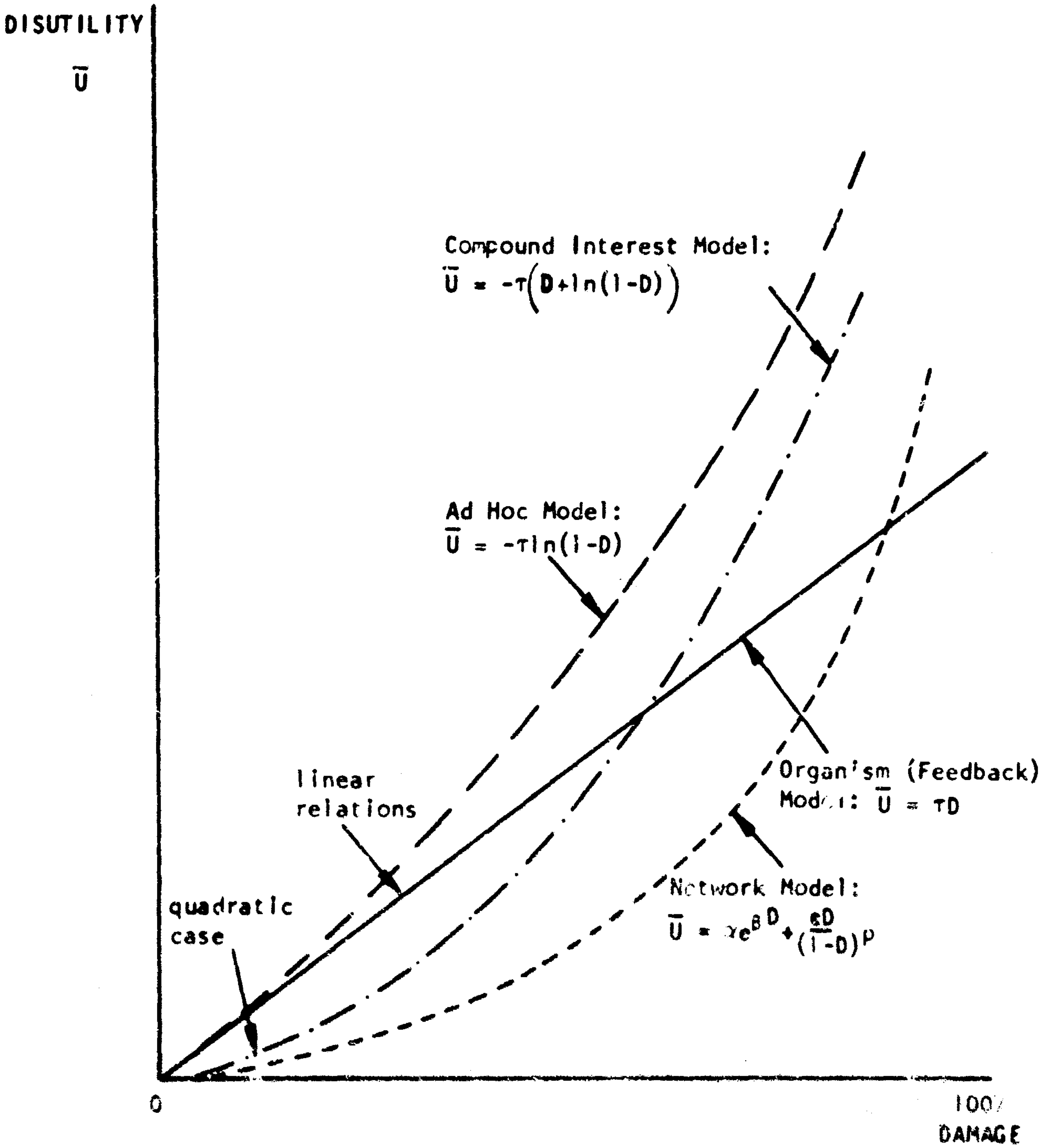
* This arises from the consideration that T is defined as the time at which recovery is complete, whence

$$1-De^{T/\tau} = 1.$$

FIGURE G.1

COMPARISON OF RECOVERY MODELS



Derivation of equations for the curves is carried out in Appendix G.

The "network repair" model (iii) we shall now consider is a special case where N junctions are assumed to be ranked in value according to a harmonic series.* We assume that the M most important junctions are destroyed. Hence the fractional damage is

$$D = \sum_{n=1}^{M} \frac{1}{n} \Big/ \sum_{n=1}^{N} = S_M/S_N, \tag{4}$$

where

$$S_M = 0.577 + \ln M + \frac{1}{2M} + \ldots . \tag{5}$$

for large values of M. Optimum recovery rate is achieved by repairing the most important junctions first.

Hence C_m, the capital available after m repairs, is

$$C_m = \frac{S_N - S_M + S_m}{S_N} \approx 1 - D + \frac{S_m}{S_N} \tag{6}$$

$$C_M = 1.$$

---

*The harmonic case is one of a class which have been called Yule distributions after the first man to derive them:

$$f(n,k) = A \int_0^{1-\delta} X^{n-1}(1-X)^{k-1}\, dX \cong A\frac{\Gamma(n)\Gamma(k)}{\Gamma(n+k)}$$

for very small values of δ. As n becomes large, the distribution asymptotically approaches the form

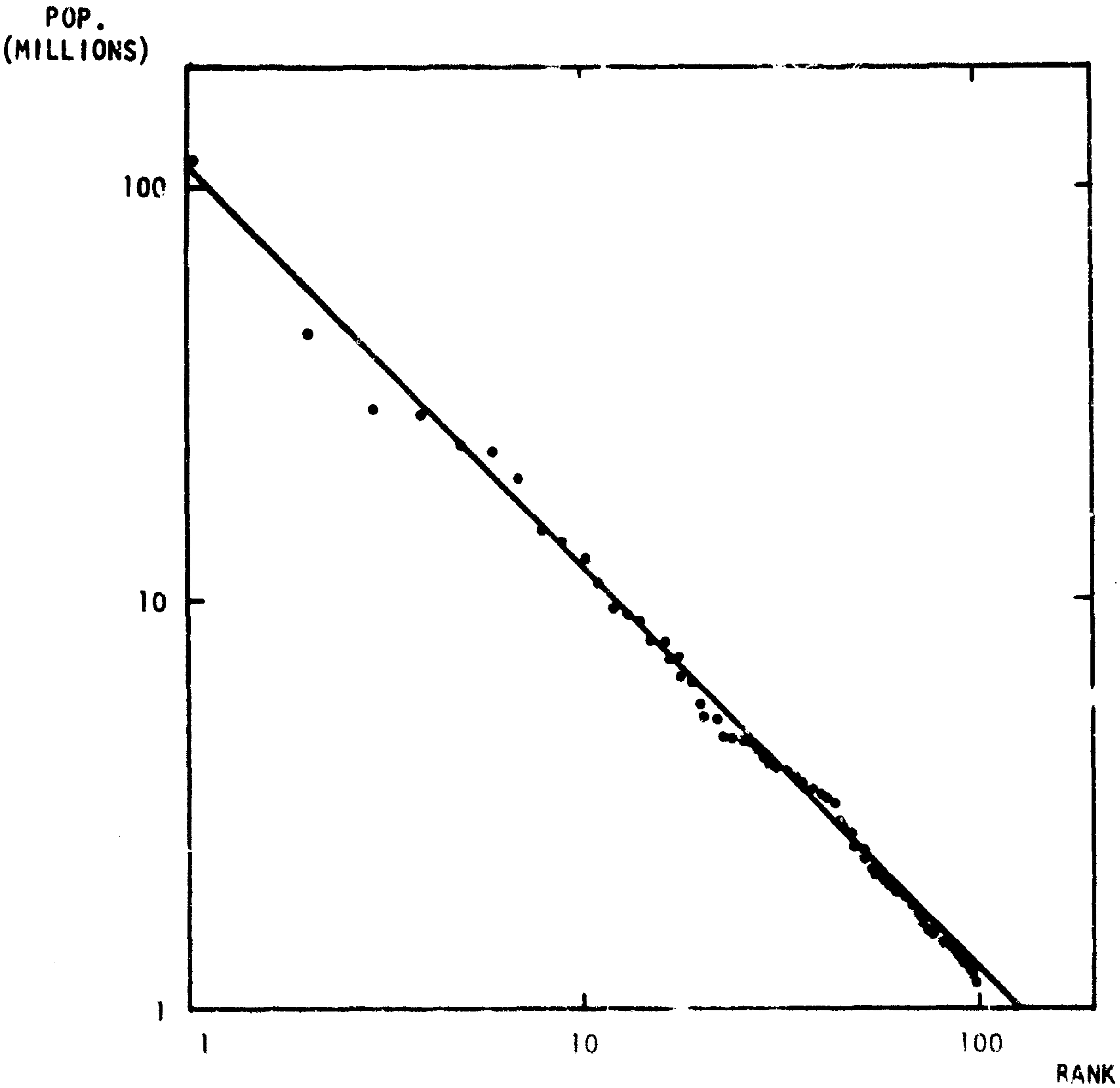
$$\lim_{n \to \infty} f(n,k) \approx An^{-k}.$$

Simon has shown how many empirical rank-ordered distributions which have been observed to fit the Yule formula can be derived from a relatively simple stochastic model.[1] This seems to account for the otherwise remarkable diversity of phenomena which fit such distributions, e.g., Pareto's law of income distribution, Lotka's law of distribution of scientific productivity,[2] Yule's law of species distribution among genera, Zipf's law of distribution of city sizes,[3] the frequency of word usage in a language,[4] etc. See also Appendix F, which suggests a similar distribution for magnitude vs. frequency of incidence for fires.

The particular choice k = 1 is applicable to several of the above distributions, notably publications, word usage and city sizes. The latter seems closest to the requirements of our "network" model, although the similarity is by no means logically compelling. Our choice of k = 1 is, therefore, essentially arbitrary, but we prefer it to other possible arbitrary choices on the grounds of similarity to the observed rank-order of cities by population. Figure G.2, taken from Zipf,[5] shows the population distribution following the 1940 census plotted on a log-scale. The straight line shows how a theoretical harmonic series rank-ordering would look.

FIGURE G.2

POPULATION VS. RANK
OF 100 LARGEST U.S. METROPOLITAN DISTRICTS (1940)



The time required for each repair will vary somewhat from a maximum in the early stages of recovery to a normal value when repairs are complete. We shall argue that the maximum time remains finite for any level of damage less than 100%. Even in an extreme case, where all normal network commerce and communication is disrupted leaving only self-sufficient farming units and "cottage industries," there will still be surviving knowledge, inventories of spare parts, vehicles, partially damaged equipment which can be cannibalized, etc.* However, one would certainly expect the time required for the m^{th} repair to vary inversely with C_m, the capital available at that point.

A funct n which fulfulls these requirements might be of the form:

$$\Delta t_m = \epsilon C_m^{-P}. \tag{7}$$

The total time for all M repairs will therefore be

$$T_M = \sum_{m=o}^{M-1} \Delta t_m = \epsilon \sum_{m=o}^{M-1} C_m^{-P} \tag{8}$$

$$= \epsilon \sum_{m=o}^{M-1} \frac{1}{[1-D + S_m/S_N]^P} \quad , P > 0$$

Note that $D - \frac{S_m}{S_N} < 1$ whence one can make a convergent power series expansion:

$$T_M = \epsilon \sum_{m=o}^{M-1} \left[1 + pD\left(1 - \frac{S_m}{S_M}\right) + \frac{p(p+1)}{2} D^2 \left(1 - \frac{S_m}{S_M}\right)^2 + \ldots\right] \tag{9}$$

The limits (0, M-1) reflect the fact that the ability to make a repair depends on the state of the network (economy) before the repair was made. In particular, the capability to make the initial repair depends on the residual capital after the damage occurs. Evidently $S_o = 0$.

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*This does assume it is possible to move around fairly freely and that some rational, directed governmental activity exists. It assumes that paralysis, chaos, anarchy and/or total demoralization do not occur or do not persist indefinitely after an attack. Some pessimists argue that they would persist. This uncertainty is a major one.

According to our standard prescription for calculating disutility $\overline{U}$, we have (replacing the integral by a sum):

$$\overline{U}_{(iii)} = \sum_{m=1}^{M} \left[1 - C_m\right] \Delta t_m = \epsilon \sum_{m=1}^{M} \frac{1-C_m}{C_{m-1}^{p}} \tag{10}$$

$$= \epsilon \sum_{m=1}^{M} \frac{D - \frac{S_m}{S_N}}{\left[1-D + \frac{S_{m-1}}{S_N}\right]^{p}}$$

$$= \epsilon \sum_{m=1}^{M} \frac{D - \frac{S_m}{S_N}}{\left[1-D + \frac{S_m - \frac{1}{m}}{S_N}\right]^{p}}$$

since $S_{m-1} = S_m - \frac{1}{m}$, $S_o = 0$.

Using the same power series expansion as above:

$$\overline{U}_{(iii)} \cong \epsilon \sum_{m=1}^{M} \left[D\left(1 - \frac{S_m}{S_M}\right) + pD^2\left(1 - \frac{S_m}{S_M}\right)\left(1 - \frac{S_m - \frac{1}{m}}{S_M}\right)^2 + \ldots \right] \tag{11}$$

As $m \to M$ the difference $1 - S_m/S_M$ rapidly approaches zero and the terms with higher power can be neglected (to a good approximation) compared with the first. Thus the higher terms only make an important contribution for relatively small values of m (say $m < \sqrt{M}$). For a given m, however, it is evident that the greater the value of D, the more terms in the power series must be considered.

By using the approximation $S_m \sim \ln m + \eta$ (where $\eta = 0.577\ldots.$) and replacing the sums by integrals, we find, in general,

$$\sum_{m=1}^{M} \left(1 - \frac{S_m}{S_M}\right)^q \cong \frac{q!M}{(\ln M)^q} \left(1 - \eta + \frac{1}{2!}\eta^2 - \frac{1}{3!}\eta^3 + \ldots \frac{(-\eta)^q}{q!}\right). \tag{12}$$

The $\frac{1}{m}$ terms can probably be safely neglected except for the case m = 1 which essentially adds a term of the form:

$$\frac{\epsilon D}{(1-D)^p}.$$

This can be verified by summing the series for the special case m = 1 and noticing that without the $\frac{1}{m}$ contribution, the lower limits of the integrals (over m) are of order unity.* The importance of the additional term is that

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*The errors arising from replacing sums by integrals are apparently of the order of unity. At any rate, the sum $\sum_{m=1}^{M} \left(1 - \frac{\ln m + \eta}{\ln M}\right)$ can be (cont'd.)

without it, $\overline{U}$ would not go to infinity as $D \rightarrow 1$ (as it should). This will be seen later.

Substituting these expressions in (9) and (11) we obtain:

$$T \cong M\epsilon \left[1 + p(1-C)\left(\frac{D}{\ln M}\right) + p(p+1)(1-C+\tfrac{1}{2}C^2)\left(\frac{D}{\ln M}\right)^2 + \ldots\right] + \frac{\epsilon}{(1-D)^P} \qquad (13)$$

$$\overline{U}_{(iii)} \cong M\epsilon \left[\frac{D}{\ln M} + 2p(1-C)\left(\frac{D}{\ln M}\right)^2 + 3p(p+1)(1-C+\tfrac{1}{2}C^2)\left(\frac{D}{\ln M}\right)^3 + \ldots\right] + \frac{\epsilon D}{(1-D)^P}\ . \qquad (14)$$

We should like to express $\overline{U}$ in terms of D and T in order to compare with the results of previous models. Note that $D/\ln M \cong 1/\ln N$, which is actually independent of damage level. Hence none of the terms inside the brackets [ ] vary from one attack to another--they are characteristics of the network (i.e. the economic system) above. Hence

$$T = \epsilon e^{D\ln N - \pi(1-D)} f(P,N) + \frac{\epsilon}{(1-D)^P} \qquad (15)$$

$$\overline{U}_{(iii)} = \epsilon e^{D\ln N - \pi(1-D)} g(P,N) + \frac{\epsilon D}{(1-D)^P}$$

$$= T\frac{g}{f} + \frac{\epsilon}{(1-D)^P}\left(D - \frac{g}{f}\right)\ . \qquad (16)$$

As we have demanded, the disutility function $\overline{U}$ is extremely non-linear in D, rapidly approaching infinity as $D \rightarrow 1$, but is roughly proportional to recovery time. Given a detailed model of some network, we could evaluate f and g numerically, but for our present purpose it is sufficient to simply

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evaluated exactly.[6] The exact expression is:

$$\frac{M(1-\pi)}{\ln M} + \frac{1}{2} - \frac{1}{2}\frac{\ln 2\pi}{\ln M},$$

the integral approximation (between limits of 1 and M) yields:

$$\frac{M(1-\pi)}{\ln M} - 1 - \frac{(1-\pi)}{\ln M}\ .$$

Clearly the terms of order unity are comparatively negligible for large values of M.

assume (for all except very small values of D where, again, the summation approximations break down):

$$\overline{U}_{(iii)} = \alpha e^{\beta D} + \epsilon D/(1-D)^{p} \qquad (17)$$

This function is plotted schematically in Figure G.1. Its similarity or dissimilarity with the other models cannot be seen so easily, since the function contains two adjustable parameters; however, it approaches infinity more rapidly than the logarithmic functions as D ——> 1, which suggests that it would generally be below the other curves for smaller values of D.

This model is not intended to be used in serious calculations of postattack disutility. The most we would claim for the three examples which have been analyzed is, perhaps, that each is slightly more sophisticated than the last. Unfortunately, greater sophistication seems to be associated with greater complexity. Nonetheless, it is likely that other improved models can be constructed and analyzed. Hopefully the future members of the sequence will incorporate features more nearly characteristic of the real postattack recovery situation, and in due course would lead to deeper insights than our first crude attempts.

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APPENDIX H

A PRELIMINARY AGRICULTURAL PRODUCTIVITY MODEL

To begin with, the meaning of the functional relationship exhibited in Figure 7.1 must be made as unambiguous as possible. The curve is intended to represent the cost of agriculture, as of 1962, assuming different hypothetical levels of demand, but no other changes in the system except those which would occur spontaneously as a result of internal readjustments. Low demand, for example, is not to be thought of as a concomitant of economic depression. To avoid misleading associations, one might imagine that the low demand case is identical with the present world except that everyone is on an austere "Chinese-type" diet, while the high demand case is the same world except that obesity becomes fashionable.*

Now suppose, further, that people's appetites were controlled independently of the economic system, e.g. by the eruptions of Vesuvius. If such an event occurred, resulting in a change in demand for food (other things therefore being equal) how would production costs alter in response? To clarify the matter further, suppose that there is no inertia in the system, i.e., the altered pattern is not dominated by past history, by immobility of farm labor or capital investment. On the other hand, suppose that the technology remains constant throughout such a hypothetical readjustment.

Production of a given crop or class of crops depends upon both extensive and intensive variables which seem to divide fairly neatly into four categories.

<u>Extensive</u>:	land acreage under cultivation	: X_1
<u>Intensive</u>:	labor and mechanical work	: X_2
	biotic inputs (e.g. seed, pest control)	: X_3
	abiotic inputs (e.g. fertilizers, water, etc.)	: X_4

For convenience, suppose the variable X_k is defined as the ratio between some absolute measure of the quantity in question (in dollars, pounds, acres, etc.) and the 1962 value of the given quantity. Let us assume also that production P varies as the product:

$$P = f_1(X_1)f_2(X_2)f_3(X_3)f_4(X_4)P_\infty \qquad (1)$$

where P_∞ is the ideal limiting agricultural production (measured in dollars, Calories, bushels or whatever unit is handy), attainable on the basis of current (1962) technology. By definition:

$$f_1(\infty) = f_2(\infty) = f_3(\infty) = f_4(\infty) = 1 \qquad (2)$$

*Very much as West Germans, today, are said to prefer fat politicians because they represent prosperity and solidity!

At first glance it might be supposed that $f_1(X_1) \cong \alpha X_1$, i.e., that increasing acreage under cultivation indefinitely would increase production in proportion. This is not true in a developed area, however, because the best land is likely to be already under cultivation and the additional acres will be progressively poorer. Not surprisingly, there are relatively few highly productive acres, or relatively few acres suited to raising very high-yield crops (such as potatoes), and many acres which are marginal for various reasons. The number in each category depends, however, on the prevailing level of agricultural investment: generally speaking, one can upgrade farmland by judicious expenditure of money on rotation, manuring, cover crops, fertilizers, irrigation, windbreaks, cross-breeding, etc. Thus if the rate of investment is high there will be more acres in the highly productive categories. Note that animal and vegetable Calories can usefully be distinguished to some extent since some poor quality land will support a certain number of grazing animals such as sheep, goats or cattle, but cannot economically be cultivated at any likely prevailing price level. Production as a function of acreage will evidently increase as more land is cultivated, but at a decreasing rate until it approaches a finite asymptotic limit:

$$\lim_{X_1 \to \infty} f_1(X_1) = 1$$

Each of the other functions behaves in a qualitatively similar way as the argument becomes large. Thus in underpopulated areas output is per unit area very nearly proportional to the amount of labor or work done by machines. As more labor (or machinery) is available production per acre goes up, but with decreasing rapidity. Eventually a labor-intensive plateau is reached where further work done will not increase production appreciably. Similarly, continued cultivation and harvesting of crops tend to reduce soil fertility. To some extent this problem can be overcome by simply doing work, e.g. on tilling, aerating, crop rotation, etc., but chemical fertilizers must also be supplied to replace elements which are in short supply--particularly potassium, nitrogen and phosphorus. Should these not be replaced somehow, productivity would drop to a lower level. On the other hand, if all necessary minerals (and water) are present, there will still be a finite limit on ultimate productivity per acre.

Another sort of asset is the specialized ecological equilibrium which is maintained with the help of such inputs as insecticides, fungicides and commercial seed. If these were removed production would drop to a lower equilibrium level. In the other direction, it appears there is again an upper limit. (The limits on what can be done by means of clever cross-breeding and eventually biological engineering are hard to foresee, and are at any rate fairly far away, but we are here only concerned with current practice and extensions thereof.)

The functional forms of f_1, f_2, f_3, f_4 are still largely arbitrary, except insofar as one can prescribe their <u>asymptotic</u> form on the basis of fairly general considerations as above. In the absence of either detailed data or a more fundamental model, we can choose functions with the correct asymptotic form and having at least one free parameter to adjust. A more sophisticated model might introduce more general functions with a larger number of free parameters. For the present it seems sufficient to take the following:

$$f_1(X_1) = 1 - \exp(-aX_1) \tag{3}$$

$$f_2(X_2) = 1 - \exp(-bX_2) \tag{4}$$

$$f_3(X_3) = 1 - C\exp(-cX_3) \tag{5}$$

$$f_4(X_4) = 1 - D\exp(-dX_4) \tag{6}$$

The problem is to determine the parameters a, b, c, C, d, D. Most of them are highly uncertain and are not really constants, e.g. $a = a(X_2, X_3, X_4)$, but we take them to be constants as a first approximation; it is to be expected that the uncertainties in the final result will probably reflect some cancellation of errors, rather than strictly additive accumulation.

To choose [a] we assume that if all available* land in the CONUS were put under cultivation (other factors being unchanged), production would increase by 50% over present levels ($X_1 = 1$)

$$\frac{f_1(\infty)}{f_1(1)} = \frac{1}{1-\exp(-a)} = 1.50 \tag{7}$$

To fix [b] we make a similar assumption, namely that if "infinite" labor were available, other things being equal, production might rise by 50%,** whence

$$\frac{f_2(\infty)}{f_2(1)} = \frac{1}{1-\exp(-b)} = 1.50 \tag{8}$$

It has been estimated by S.R.I. that doubling the <u>human</u> labor force would increase productivity by 10% (see Figure H.1).[1] However, much farm work today is actually done by machines, so that doubling total effective labor (i.e. work done) would presumably be equivalent to a much greater increase in human labor.

The next two parameters, c and C, may be determined by making two assumptions, namely that doubling the current rate of use of fertilizers would increase production 12%, whereas cutting it to zero would result in a 25% drop (see Figure H.3). Thus:

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*"Available land" would include some that is currently cultivated for non-food crops, particularly tobacco and cotton, in addition to suitable land which is fallow or belongs to municipalities, parks, reservations, military installations or residential estates. Incidentally, the estimate of 50% is the author's own; others would disagree--perhaps by substantial factors.

**This is a difficult estimate to make, since it involves "averaging" over many different crops. In some cases, e.g., grain, one suspects that infinite labor inputs would not make this much difference; in other cases, e.g., vegetables and orchard crops, it might matter more.

FIGURE H.1

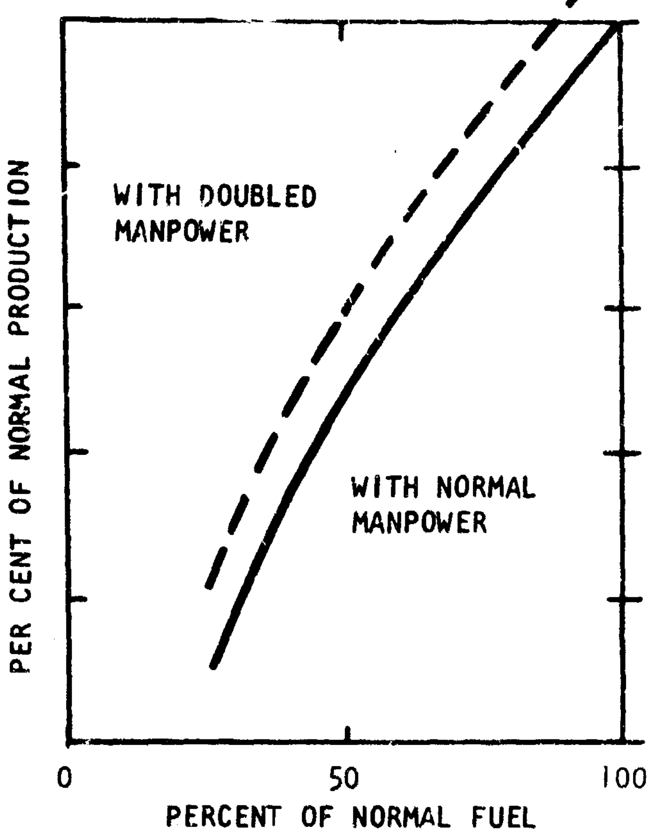


FIGURE H.2 S

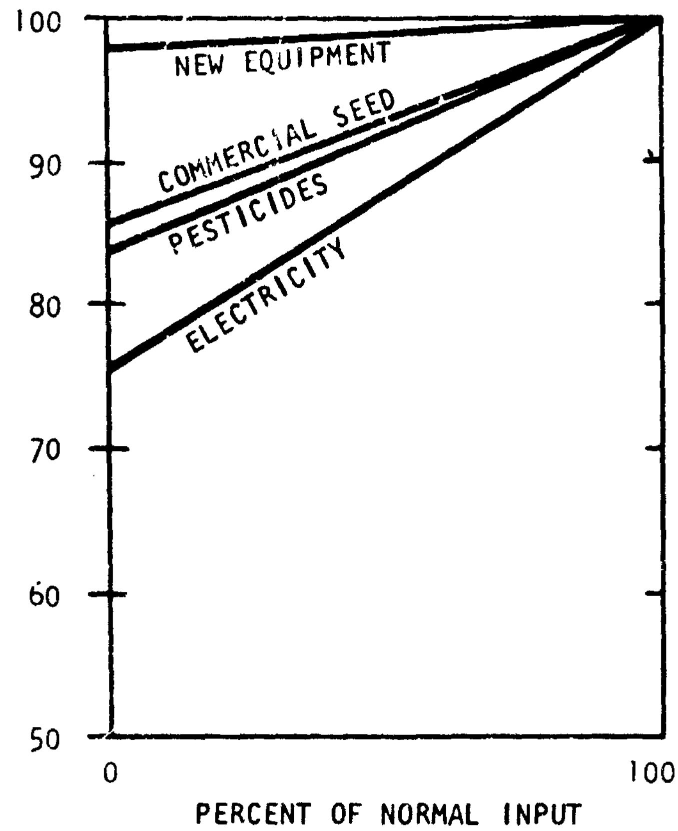
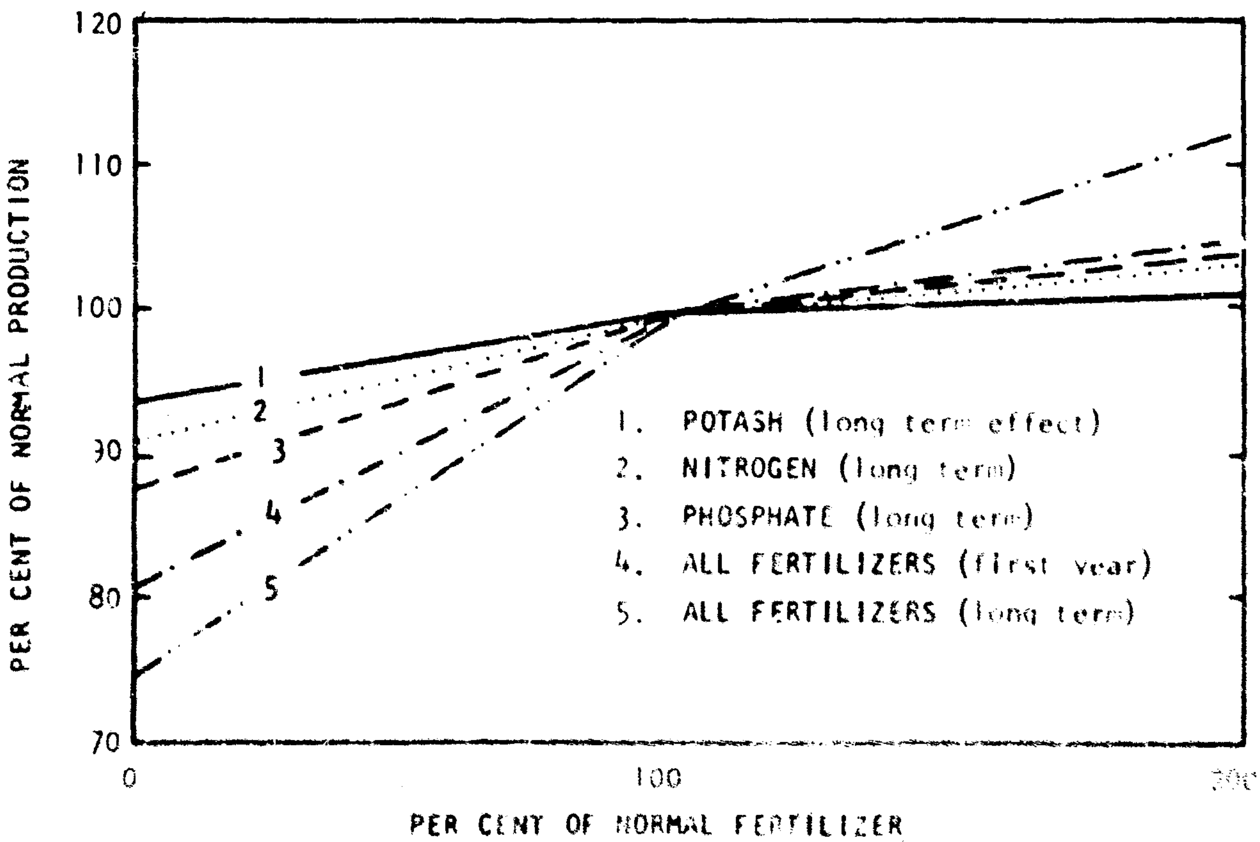


FIGURE H.3



$$\frac{f_3(2)}{f_3(1)} = \frac{1-C\,\exp(-2c)}{1-C\,\exp(-c)} = 1.12 \qquad (9)$$

$$\frac{f_3(0)}{f_3(1)} = \frac{1-C}{1-C\,\exp(-c)} = .75 \qquad (10)$$

Finally, the parameters D,d are fixed by the assumption that withdrawal of all commercial seed and pesticides would decrease over-all production by 30% (see Figure H.2) whereas in the other direction the potential increase might be 20%. The latter estimate is partly based on statistics, given in Table H-1.[2]

$$\frac{f_4(0)}{f_4(1)} = \frac{1-D}{1-D\,\exp(-d)} = .70 \qquad (11)$$

$$\frac{f_4(\infty)}{f_4(1)} = \frac{1}{1-D\,\exp(-d)} = 1.35 \qquad (12)$$

Solving the equations (7-12) one obtains:

$$\begin{aligned} a &= 1.10 \\ b &= 1.10 \\ c &= 0.735 \\ C &= 0.39 \\ d &= 0.62 \\ D &= 0.48 \end{aligned} \qquad (13)$$

The functions $f_1, \ldots f_4$ are now fixed. It remains to indicate how a change in demand (assumed equal to production) will be felt in terms of changes of the various inputs.

One final *ad hoc* assumption is required to completely determine the model: namely, that changes in each of the four variables X_1----X_4 occur in the same ratios, and that these ratios can be expressed equivalently in terms of a convenient economic index (e.g. fraction of GNP):

$$\frac{\Delta X_1}{X_1} = \frac{\Delta X_2}{X_2} = \frac{\Delta X_3}{X_3} = \frac{\Delta X_4}{X_4} = \frac{\Delta X}{X} = \Delta \ln X \qquad (14)$$

$$\Delta \ln P = \left[\frac{aX_1\exp(-aX_1)}{f_1} + \frac{bX_2\exp(-bX_2)}{f_2} + \frac{cCX_3\exp(-cX_3)}{f_3} + \frac{dDX_4\exp(-dX_4)}{f_4}\right] \Delta \ln X \qquad (15)$$

TABLE H-1

PROD[illegible]ION LOSSES OF CROPS (1942-51)

	Insects (as pests)	Disease	Total
cotton	15% (bollweevil 10.1%)	17.5%	32.5%
dry beans		11.5%	11.5%
corn	3.3% [earworm 1.2%; E. borer 1.9%; SW " 0.2%]	4.8%	8.1%
oats	0.6% (greenbug)	21.3%	22.9%
rice		5.9%	5.9%
wheat	2.0% [stem sawfly 0.2%; Hessian fly 0.9%; Greenbug 0.9%]	6.6%	8.6%
soybeans	(chinch bug)	8.3%	8.3%
peanuts		19.0%	19.0%
sugar beets		16.9%	16.9%
soybeans		12.5%	12.5%
alfalfa (hay)	9.3% (pea aphid & spittlebug)	36.0% [27% bacteria; 6% viruses; 3% nematodes]	45.3%
alfalfa (seed)	35.0% (lygus)	9.0% [6% virus; 3% nematodes]	44.0%
citrus fruits	14.0% Florida 5.0% California	3.0%	17.0% Florida 8.0% California
grapes		4.0%	4.0%
apples	14.0% (codling moth 11%) (maggot 3%)	6.0%	20.0%
snap beans	9.0% (Mex. bean beetle)	22.0%	31.0%
cabbage		8.0%	8.0%
lettuce		12.0%	12.0%
potatoes	15.6%	20.1%	35.7%
peas	2.4% (weevil)	23.0%	25.4%

If we restrict attention to changes from the 1962 equilibrium considerable simplification in the bracketed term is possible since

$$X_1(1962) = --- = X_4(1962) = 1.$$

Hence

$$\Delta \ln P = \left[\frac{ae^{-a}}{1-e^{-a}} + \frac{be^{-b}}{1-e^{-b}} + \frac{cCe^{-c}}{1-Ce^{-c}} + \frac{dDe^{-d}}{1-De^{-d}}\right] \Delta \ln X \qquad (16)$$

Substituting all the values previously calculated, and identifying the term in square brackets [..] as K_0, one obtains:

$$K_0 = 1.49 \cong 3/2 \qquad (17)$$

Integrating (16) we find

$$\ln P = K_0\left(\ln X + \ln K_1\right) \qquad (18)$$

or

$$P = \left(K_1 X\right)^{K_0} \cong \left(K_1 X\right)^{3/2} \qquad (19)$$

where K is evidently interpretable as 1962 (equilibrium) production, and X is a suitable economic index which we are free to interpret as % of GNP. The slope 3/2 of the curve in Figure 7.1 is derived from equation (19).

The foregoing "calculation" is not satisfying, either as an exercise in mathematical model building, or as a "quick and dirty" approximation to generate useful numbers. Although one relevant number has been produced, the reader may be forgiven for wondering whether its importance justifies the sloppiness of the procedure by which it was obtained. As in some other instances in this report, our primary justification for making the attempt is that it might conceivably stimulate a more serious treatment of the same problem by another investigator.

References

1. K. Moll, J. Cline, et. al., Review of Postattack Farm Problems, Stanford Research Institute, Menlo Park, California, December 1961.

2. U.S.D.A. Losses in Agriculture, Washington, D. C., June 1954.

APPENDIX J

NUTRITIONAL FACTORS IN A POSTATTACK ENVIRONMENT

One of the penalties of being an advanced product of evolution is that man--as well as other higher animals--has lost the ability to synthesize from his basic components some of the chemicals which constitute his protoplasm and supply energy for metabolism. In the past fifty years, considerable research has been devoted to isolating both the basic raw materials necessary in the human metabolism and those more complex substances which must be supplied essentially in a prefabricated form. These are classed as energy sources, proteins (amino acids), vitamins, essential fatty acids (lipids), and minerals. In a postattack environment the availability of each element of nutrition would probably be affected in a different way.

1. Calories*

It cannot be stated categorically that food energy would be plentiful in a postattack environment, but Caloric shortages, if they did occur, would probably be accompanied by much more severe shortages or imbalances of other nutritional elements. On the average, carbohydrates provide 4.1 Calories/gram; fats, 9.5; and proteins, 5.7. Daily requirements range from 2000 to 5000, depending on age, weight and activity. Energy content or Caloric value of standard foods is well known, frequently tabulated, and readily available. For this reason, it tends to be somewhat overemphasized in many popular discussions of nutrition. Indeed, there may be some justification for this when the problem being considered is to supply a diet meeting certain elementary requirements under special conditions for some limited period of time, as in a fallout shelter environment.

2. Proteins (Amino Acids)

Proteins are found in every living organism, in every part of the body, and are, in fact, the *sine qua non* of life. All proteins which are ingested must be broken up by the digestive system into component amino acids from which specific needed body proteins are constructed. All of the common proteins found in plant and animal foodstuffs are constructed from approximately 25 basic amino acids. Many of the 25 amino acids can be synthesized in the human body (listed in Table J-1); although some of these need additional supplements from the diet. The eight "essential" amino acids which must be supplied from the diet are given in Table J-2. Ratios of these essential amino acids vary from food to food, but in vegetable sources three amino acids, tryptophan,

*To avoid confusion we follow the standard convention and define 1 Calorie = 1000 calories, where the (uncapitalized) calorie is the amount of heat required to raise the temperature of 1 gram of water 1 degree Centigrade.

Table J-1

Amino Acids Made by the Body

Glycine	Tyrosine
Glutamic acid	Cystine
Alanine	Cysteine[a]
Proline	Hydroxyglutamic acid
Hydroxyproline	Norleucine
Aspartic acid	Di-iodo-tyrosine
Serine	Histidine[b]
	Arginine[b]

Table J-2

Essential Amino Acids[1]
Daily Requirements

Amino Acid	Value proposed tentatively as minimum grams per day	Value which is definitely a safe intake grams per day
Tryptophan[c]	0.25	0.50
Phenylalanine[d]	1.10	2.20
Lysine	0.80	1.60
Threonine	0.50	1.00
Valine	0.80	1.60
Methionine[a]	1.10	2.20
Leucine	1.10	2.20
Isoleucine	0.70	1.40

[a]Cystine and cysteine are closely related chemically. Cysteine is very unstable and is easily oxidized to cystine. Both, along with methionine, are sulfur-containing amino acids. Presence of suitable amounts of cystine found to reduce by 80-89% the amount of methionine required.

[b]Histidine and arginine are essential for children.[2]

[c]Tryptophan can be converted to niacin, with the help of the co-enzyme pyridoxine (B_6).

[d]On diet devoid of tyrosine. Presence of suitable amounts of tyrosine may reduce the phenylalanine requirement by 70-75%.

Note: The so-called essential amino acids were distinguished experimentally from the inessential ones by "nitrogen balance" only. An inessential amino acid is defined as one which, when absent from the subject's diet, induces no change in the state of the nitrogen balance. The mere fact that there is no change in the nitrogen balance after an experimentally induced amino acid deficiency does not necessarily mean that the deficient amino acid was not an "essential" one in some sense.[3]

lysine and methionine are consistently rare. In the most plausible post-attack source of supplemental dietary protein--brewers' yeast--lysine and tryptophan are supplied adequately but methionine (and cystine) are not. Methionine is the common denominator for both of these cases and might be a critical factor in postattack diets. Tables of amino acid contents of common foods are supplied in all texts on nutrition and will not be reproduced here.

3. Vitamins

Vitamins are, loosely speaking, chemical substances required by the body in small quantities for normal functioning, which are not otherwise classified (e.g., as amino acids or fatty acids). New candidates for vitamins are at least tentatively proposed in the technical literature every few months. Until such time as the human body chemistry is much more thoroughly understood than it is at present, it will not be safe to replace natural foods for any substantial period of time (say, six months or longer) by artificial substitutes* for the simple reason that the synthetic versions contain only those elements which are known and, of course, leave out vitamins and chemical substances of importance whose role in the metabolic process are not as yet understood. For a list of the recommended daily vitamin requirements, see Table J-3.

a. B-Complex Vitamins

To a certain extent the B-complex vitamins can be synthesized by intestinal bacteria. However, these symbiotic bacteria require para-aminobenzoic acid (PABA) and, possibly, lactose and poly-unsaturated fat for their own needs. They are susceptible to sulfa drugs as well as the antibiotics, streptomycin, aureomycin and penicillin. Secondary results of a thermonuclear war, such as widespread radiation, lowered disease resistance, and a breakdown of sanitation and public health controls, might lead to epidemics of enteric diseases ranging from vague diarrheas and "intestinal flu" to bacillic dysentery and typhoid fever. These diseases, or their treatments,** often interrupt the useful activities of intestinal bacteria leading eventually to B-vitamin deficiencies, some of which would go unrecognized. The consequences for populations weakened by radiation and under severe environmental stress may be very serious.

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*Although this has been done successfully for rats in a laboratory environment. However, (i) much more is known about rat nutrition than human nutrition, since rats are much easier to experiment on; (ii) rat nutrition and human nutrition are emphatically not the same (for example, rats do not require vitamin C); and (iii) the artificial diets are only known to be adequate for an animal in a cage leading an "easy" life. (This is an important remark.)

**Sulfonamides are chemically similar to PABA and are taken up by bacteria in preference to it. Hence the value of sulfa drugs against bacillary dysentery.

Table J-3

Recommended Average Daily Adult Vitamin Requirement

A	5000 USP Units or 1.5 mg.
D	400 USP units in pregnancy, childhood and adolescence.
E	14-19 mg.; deficiency is not likely in a "normal" diet due to widespread distribution of vitamin E in foods.
C	75 mg.--optimal adult requirement.
B Complex:	
B_1 (thiamin)	0.5 mg. per 1000 Calories.
B_2 (riboflavin)	1.8 mg.
Niacin	20 mg. or 25 mg. if taking sulfa drugs.
B_6 (pyridoxine)	1.2 mg.[a]
Pantothenic acid	Unknown, but probably less than 5 mg. (A deficiency disease has not been identified for man.)
Folic Acid	Unknown, but probably less than 0.2 mg.
B_{12}	Unknown, but probably less than 1 microgram[b]
Choline	Less than 500 mg. (Diet usually furnishes 250-600 mg.)
Inositol	Less than 1 gm. "safe" level of intake.
Biotin	Unknown.
Para-aminobenzoic acid (PABA)	Unknown.
K	Adult requirement not established. 1 mg. daily during last month of pregnancy.
P (bioflavinoids)	Not established.

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[a]In animals the B_6 requirement is increased by methionine and by sucrose in the diet; it is apparently reduced by choline, essential fatty acids, biotin and pantothenic acid.

[b]This amount will induce remission of experimentally induced pernicious anemia. B_{12} deficiency has been observed in long-standing vegetarian diets. This has some relevance to possible post-attack situations. A "normal" diet is estimated to contain 8-15 micrograms.

In addition to the B-complex vitamins listed in Table J-3, there are several other possibilities being reported on in the literature, for example, lipoic or thioctic acid, vitamins B_{13}, B_{14} and pangamic acid (B_{15}). There are also possibly other B-vitamins called variously antifatigue, antitoxic or antistress vitamins which appear to be unnecessary under normal conditions or needed only in very small amounts such as might be produced by bacteria in the intestines. However, under conditions of stress such as produced by drugs, or chemicals, or infections, pain, noise, fatigue, or other factors (including radiation sickness) these vitamins, which seem to be present mainly in animal liver, might be extremely important. Davis[4] cites laboratory animals made to swim in ice water. Fed normal diets, they lived only three to ten minutes; but when given extra liver they survived immersions as long as two hours under the same conditions.

b. Vitamin A

Vitamin A is found in all green vegetables as well as many root crops which may be safer to eat, and can be stored better than leafy vegetables. Fish oils and seed oils are the major commercial source, and, given a reasonable degree of social organization, fishing as an industry should continue. Many commercial fish canneries are in relatively unpopulated areas, e.g., Alaska, Oregon, Maine, Samoa, Nova Scotia, etc. Critical situations are most likely to arise, if at all, as a result of transportation or distribution breakdowns rather than basic shortages. The fact that Vitamin A is easily stored in the body (mainly in fatty tissues) tends to make short-term problems unlikely.

c. Vitamin D

In a postattack situation where large numbers of people may be confined indoors for long periods in order to minimize contact with radioactive contamination, a vitamin D shortage is a real possibility. Commercial vitamin D cannot be synthesized artificially and is obtained from yeast or from fish liver oils,* although any animal liver is a good source and any animal fat is likely to contain at least some. Vitamin A and vitamin D are almost always sold together commercially, so the above comments in regard to vitamin A apply largely to vitamin D also.

Exposure to ultraviolet light enables the normal adult body to produce its own vitamin D supplies. Hence sun lamps (or ultraviolet lamps) are the only real requirement for all except young children.

d. Vitamin E

Among other functions (mostly not well understood), vitamin E is an antioxidant which, in the body, protects vitamin A and other unsaturated fatty acids against oxidative destruction. The liver of an animal deprived of vitamin E tends to be rapidly depleted of its vitamin A content.

*By irradiating the component sterols with ultraviolet light.

The vitamin (along with B_6) also plays a role in the metabolism of fatty acids, with which it is frequently associated in the diet. The antioxidant property of vitamin E may protect red blood cells from hydrogen peroxide, which is produced in the blood from water molecules by ionizing radiation. However, despite this useful property, vitamin E appears to have no effect in mitigating the effects of radiation, at least when the vitamin is supplied in excess doses. On the other hand, it seems possible that a deficiency of vitamin E would degrade the body's resistance to radiation.

e. Vitamin C, P

Apart from its well-known antiscorbutic activity and other functions, vitamin C seems to be particularly important in the production of phagocytes and antibodies. Since the principal result of radiation sickness is degradation of the body's ability to fight infections by producing antibodies, vitamin C would be of critical importance in a postattack environment. Vitamin C is also a rather generalized antistress factor, enabling the body to adjust to temperature extremes and other environmental influences. Massive doses (up to 1000 mg.) are sometimes recommended, although the scientific basis for this is thin, since the kidneys rapidly eliminate excess vitamin C from the blood stream. The bioflavinoids (vitamin P), found especially in citrus fruits, may play a role in ascorbic acid metabolism and, possibly, in promoting tissue regeneration (e.g., following burns).

f. Vitamin K

This vitamin is essential in the production of prothrombin, which, in turn, is required for the formation of fibrin, one of the constituents of blood clots. In humans, vitamin K is normally supplied by intestinal bacteria, with the exception of newborn infants, whose intestines are sterile. The principal cause of deficiency in adults is likely to be prolonged treatment by antibiotics or possibly some other severe disturbance in the intestinal tract.

4. Essential Fatty Acids

Only three of the many fatty acids are termed "essential" because the body requires but does not synthesize them. These are linoleic acid, linolenic acid and, to a certain extent, arachidonic acid. Linoleic acid is the most important for dietary purposes, although to some extent it can be substituted for by linolenic acid. Linoleic acid is found in nuts, seeds, kernels of cereal grains and animal fats, especially liver and other glands. Soybean oil, cottonseed oil, and corn oil contain up to 50% linoleic acid (the "poly-unsaturates" of modern dietary literature). Since the most plausible postattack diet would depend heavily on whole cereal grains (rather than refined flour, etc.), the ratio of unsaturated to saturated fatty acids in the diet would probably be higher than at present. In this respect, at least, the population would probably be healthier than it is n .

5. Minerals

As a general rule, minerals are taken up by plants in sufficient quantities to supply human needs, providing the plants are grown in soil containing the requisite minerals in the first place. Calcium and phosphorus, generally used together by the body, are primarily derived from milk and dairy products--about 73% presently in the United States. Calcium is important because the most dangerous long-lived component of fallout, Sr-90, is taken up by the body as a calcium surrogate. If calcium is in short supply, more radio-strontium will be absorbed by the tissues and incorporated into bones and teeth. Hence an adequate supply is important while the normal sources are unavailable (e.g., due to contaminated forage). If mineral supplements are supplied, they should contain calcium and phosphorus (e.g., manufactured from bone meal) as well as iron and iodine. Other possibilities are to use iodized salt and reprocess limestone into a soluble calcium powder. See Table J-4 below for daily mineral requirements.

Table J-4[5]

Element	Approximate % of Adult Human Body	Minimum Daily Requirement	Recommended Daily Intake
Calcium[a]	2.2	.55 gm/day	1.0 gm/day
Phosphorus[b]	1.2	.3 "	.6 "
Potassium	0.35	1.5 "	
Sulfur	0.25	.8 "	
Chlorine	0.15	.8 "	
Sodium	0.15	.2 "	
Magnesium	0.05	.15 "	
Iron	0.004		12 mg/day[d]
Manganese	0.0003		
Copper	0.00015		1 mg/day[d]
Iodine	0.00004	.014 mg/day	excess stored
Cobalt	c		
Zinc	c		
Molybdenum	c		
Others of more doubtful status			

[a]Estimates vary widely.

[b]Percentage varies with that of calcium. Ca/P ratio is normally just under 2.

[c]Quantitative data seem insufficient for numerical expression here.

[d]Higher during pregnancy and lactation.

6. Remarks

In speaking of dietary requirements, it should be understood that we are not necessarily referring to the absolute minimum requirements for physical survival. There is practically no evidence which would allow one to define such a minimum. It is true that human beings may survive (e.g., in a postattack environment) on diets which are extremely deficient. Many of the symptoms of vitamin or amino-acid deficiency such as pellagra, rickets, kwashiorkor, scurvy, beri-beri, and pernicious anemia are not in themselves fatal. In general, the results of shortages are, at first, a general weakening of the organism (especially its ability to withstand environmental stress and disease). As the deficiency continues, a chain of events is initiated which ends in death if the supply is not renewed. To reverse the process is not a simple matter. After a prolonged deficiency it is not possible to build up the supply in the blood stream and the cells to its optimum point in a short time. Generally it takes months or years for the proper equilibrium to be restored.

The most likely deficiencies in a postattack environment would be the essential amino acids and the water-soluble vitamins (especially those normally obtained from foods of animal origin, such as meat, milk and eggs), because these two food elements must be restored almost daily.* The water-soluble vitamins (B-complex and C) are not only not retained in the human body to any extent, but they are easily destroyed in stored foods by heat, light or various enzymes.

References

1. H. C. Sherman and C. S. Lanford, Essentials of Nutrition, 4th ed., New York: Macmillan (1957), p. 103.

2. A. A. Albanese, Journal of Clinical Nutrition, Vol. 1, no. 1, (1952), p. 51

3. L. E. Holt and A. A. Albanese, Transactions of the American Association of Physicians, LVIII, (1943), p. 143.

4. A. Davis, Let's Eat Right to Keep Fit, New York: Harcourt, Brace & World, Inc., (1954), p. 68.

5. Adapted from Sherman & Lanford, op. cit., p. 120.

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*It should be made clear that supplies of these substances are present at all times in the body, and are not all used up in a single day. The requirements listed are essentially the quantities which would be required by the metabolism in a day without depleting the active supply or "rotating inventory." In the case of vitamin C, for example, it has been found experimentally that three or four months would have to pass before the body's supply of vitamin C was reduced to zero, assuming no special need for the vitamin arose during the interim.